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DIVISION OF MINES AND MINING  
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Report of Investigations  
No. 6

**Relation of Geology to Mineralization in  
the Morton Cinnabar District**

Lewis County, Washington

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By  
J. H. MACKIN



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## FOREWORD

The cinnabar occurrences of the Morton district have been extensively prospected during the 30 years that they have been known, and many mines have been opened and operated with varying degrees of success. Some of the mining organizations paid little attention to ore-development, being satisfied to take only the readily available high-grade ore; others expended large sums of money on extensive development, on ore-beneficiation, and on elaborate reduction plants. The returns from these ventures have varied widely. Although more than one-half million dollars in mercury has been produced, only a few of the smaller mines and occasional phases of the larger operations have been profitable.

Interest in the district has risen and declined during various periods. At present it is at a low ebb, though a recurrence of activity will doubtless take place many times in the future as it has in the past. There is no reason to assume that profitable operations cannot be carried on despite the unfortunate experiences of some operators. One cause of difficulty in the past has been a lack of understanding of the principles governing the cinnabar mineralization. "Trial and error" rather than scientific methods were commonly used in mine development. Some careful geologic work was done at various times, but the results of such work have not been generally available. The district is large, and subsurface conditions are imperfectly known; it is probable that a better understanding of the ore occurrences will lead to new and successful operations.

The present report is, therefore, considered a most valuable contribution to the information on an important area and a valuable resource. The investigations upon which it is based were made by Dr. J. Hoover Mackin, Associate Professor of Geology, University of Washington. In 1942 he was retained as Consulting Geologist by the Northern Pacific Railway Co. to study these and various other mineral occurrences throughout the State, that might be of value to the war effort. Through the courtesy and cordial cooperation of Dr. Mackin, and of Mr. J. M. Hughes, Land Commissioner, and Mr. V. A. Gilles, Chief Geologist, Northern Pacific Railway Co., permission has been given to publish this report, thus making it more generally available to the mining industry than it would otherwise be.

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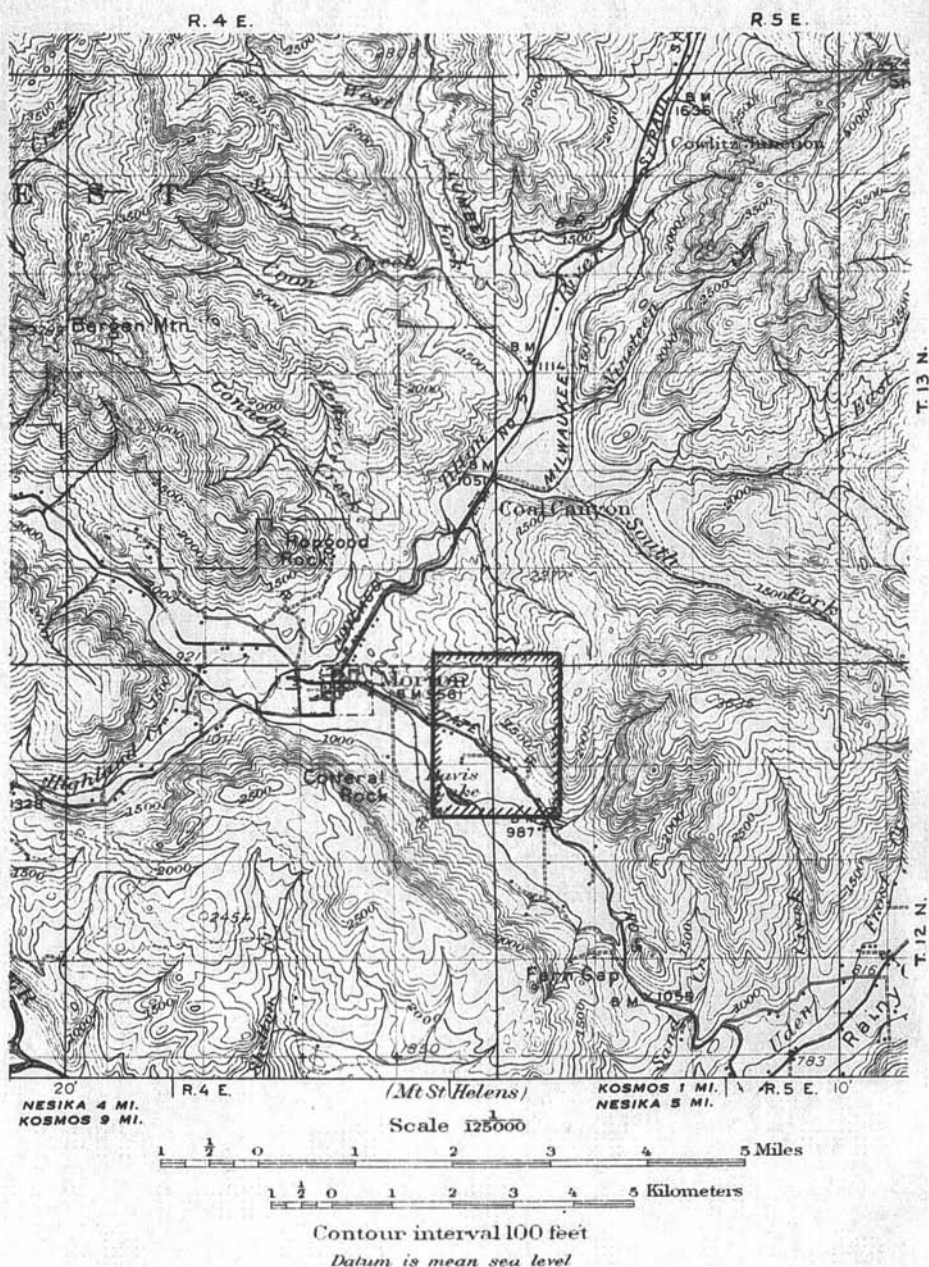


Figure 1.- Portion of the United States Geological Survey's Eatonville quadrangle, showing the general location of the Morton district. The outlined rectangle east of Morton indicates the area included in plate 1.



# RELATION OF GEOLOGY TO MINERALIZATION IN THE MORTON CINNABAR DISTRICT, LEWIS COUNTY, WASHINGTON

By J. H. MACKIN \*

## INTRODUCTION

The Morton cinnabar district is  $1\frac{1}{2}$ -2 miles east of the town of Morton, Washington. The connecting Roy and Barnum-McDonnell (Roy—B.-M.) properties, having 7,500 to 8,000 feet of underground workings, are in the  $N\frac{1}{2}NW\frac{1}{4}$  sec. 7, and the  $S\frac{1}{2}SW\frac{1}{4}$  sec. 6, T. 12 N., R. 5 E. A considerable number of smaller workings and prospect tunnels are in a belt extending northward from the Roy—B.-M. properties, chiefly in the  $W\frac{1}{2}$  sec. 6; one abandoned mine and several trenches and pits are in the  $NE\frac{1}{4}$  sec. 1, T. 12 N., R. 4 E. General topographic relations in the Morton area are shown in figure 1, a portion of the United States Geological Survey's Eatonville quadrangle; detailed topography and certain structural features in the known mineralized area, as well as the location of mines and prospects, are shown in plate 1.

The purpose of this study was to determine, from accessible underground workings and surface exposures, the geologic factors which controlled the emplacement of the mercury ores in the Morton district as a basis for evaluating the possibility of extension of the deposits. Emphasis was therefore placed on the bearing of structure and stratigraphy on mineralization. In several instances relationships, recognized for the first time when the geology of adjacent openings was plotted in the office, appear to be of some importance in possible future exploitation of certain of the mines; but the specific purpose of the investigation does not justify the expense that would be involved in the gathering of additional data needed for the solution of these local problems. No samples were taken during the course of the study; occurrences of 'ore' were inferred from the locations of stopes, showings of cinnabar, or the reported locations of stopes in those parts of the workings that are not accessible at the present time. It is evident, therefore, that this report cannot serve as a basis for determining the value of any of the properties examined, or, except in a general way, for the planning of their future development.

The field work, upon which this report is based, was carried on during September, 1942, a total of 13 days being divided as follows: 5 days in the Roy-B.M. mines, 4 days in other underground workings, and 4 days in the study of surface geology and

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topography. The structural and topographic map (pl. 1) and base maps of the mine workings (pl. 2) were prepared (except as indicated on plate 2) by Mr. L. V. Mullen and Mr. L. T. Christian of the Northern Pacific Railway Co. Geological Division staff. Mr. Jack Rosborough, of Morton, acted as a guide and assistant in the subsurface work. Mr. J. T. Mullen, Jr., of the Northern Pacific Railway Co. Geological Division staff, arranged for permission to examine the various properties and made numerous helpful suggestions during the progress of the work and the preparation of the report. Responsibility for statements and opinions rests wholly on the writer. It should be evident from the foregoing indication of the time spent in the area that this study was definitely of a reconnaissance nature; stratigraphic measurements and correlations in the several properties were rarely checked with the care that would be required in a detailed survey of any of the properties, as such, nor were field classifications of rock types, except in one instance, checked by microscopic study. The time devoted to the working out of local structural features of the mineral deposits was, in so far as possible, made roughly proportionate to the bearing of these features on habits of mineralization of the area as a whole.

### HISTORY AND PRODUCTION

The original discovery of mercury in the Morton district is said to have been made in 1913 by Edward Barnum, who noted the presence of cinnabar in a seam of coal. According to local sources of information, mercury was first produced in 1916, when 75 flasks were recovered from 47 tons of ore<sup>①</sup>. Active development of the district, however, began with the opening of the Barnum-McDonnell mine in 1926. The total output of the district as a whole from 1926 to 1940, as recorded in Mineral Resources and (after 1931) in Minerals Yearbook, U. S. Bureau of Mines, was as follows:

*Mercury production of Morton district, 1926-1940*

Year	Flasks	Value	Year	Flasks	Value
1926 .....	489 <sup>①</sup>	\$44,491	1934 .....	330	\$24,375
1927 .....	566 <sup>①</sup>	65,996	1935 .....	106	7,631
1928 .....	②	②	1936 .....	②	②
1929 .....	1,397	170,637	1937 .....	②	②
1930 .....	1,079	124,095	1938 .....	②	②
1931 .....	560	48,917	1939 .....	None	None
1932 .....	407	23,575	1940 .....	65	②
1933 .....	②	②	Total reported 4,999		\$509,717

① 75-pound flasks in 1927 and preceding years; 76-pound flasks in succeeding years.

② Production figures grouped with those of other states.

③ See also: McCaskey, H. D., Quicksilver: U. S. Geol. Survey Mineral Resources U. S., 1916, pt. 1, p. 769, 1919.

The available data are in some instances so arranged that it is possible to ascertain the yearly production of individual mines and to determine roughly the tenor of the ores. Thus in the first year of operation (1926) the Barnum-McDonnell mine produced 489 flasks from 900 tons of ore, indicating a recovery of about 47 pounds per ton. The total production of the mine from 1926 to 1929, inclusive, was 1,265 flasks<sup>①</sup>. In 1931 this property produced 441 flasks from 11,115 tons of ore, or about 3 pounds per ton. The Roy-Fisher property, adjacent to the Barnum-McDonnell mine, was developed in 1926 and 1927; it produced about 2,500 flasks in 1928-29<sup>②</sup>, and 1,079 flasks in 1930. The 1931 production of 1,581 tons of ore from the Roy-Fisher property averaged 0.25 percent mercury, or about 5 pounds per ton. Most of the other mines in the district were opened between 1931 and 1936. Their production was evidently insufficient to counteract the steady decline in output of the district resulting from decreased activity on the Barnum-McDonnell and Roy-Fisher properties between 1930 and 1940.

The Roy-Fisher property produced 65 flasks from 1,000 tons of ore in 1940 and has been operated intermittently on a small scale since that time. In 1940 the lower Barnum-McDonnell haulage tunnel was reopened and a 300-ton mill, with flotation equipment designed for treatment of low-grade ore, was erected on the Barnum-McDonnell property. Chiefly because of failure to find ore, and possibly in part because of difficulty with the flotation process, the operation ceased after a few test runs. In 1942-43 the mill was dismantled, and the track and air lines were removed from the mine.

The only mining now (1943) in progress in the district is a small-scale operation in a part of the Roy workings.

## PRINCIPAL MINING DEVELOPMENT

### THE ROY—BARNUM-McDONNELL MINES

#### GENERAL GEOLOGY

The rocks penetrated by the Roy—B.-M. mine workings are—(1) a sequence of sediments including shale, siltstone, and tuffaceous sandstone; and (2) basic sills, dikes, and other igneous bodies, intrusive into the sediments. The sedimentary rocks contain a number of beds of coal and certain fossil types suggesting brackish water and estuarine conditions of deposition; the sequence is undoubtedly part of the Eocene Puget group, which underlies much of the area adjacent to Puget Sound and the western flank of the Cascade Mountains. The prevailing strike in the mine area is north; the dip averages about 20° to the east. Surface exposures 1 mile to

① Build new quicksilver plant in Morton district: Eng. and Min. Jour., vol. 129, p. 479, 1930.

② Idem.

the west show high easterly dips, indicating that the mines are located in the east limb of a major north-south anticline which parallels the regional trend of fold structures.

Mineralization in both mines was controlled by varying degrees of perviousness in the east-dipping sedimentary beds, and by brecciated zones and/or gouge along three faults: the Barnum normal fault, trending north and dipping  $35^{\circ}$ - $60^{\circ}$  W.; the Black Wall thrust, trending N.  $10^{\circ}$ - $15^{\circ}$  W. and dipping  $20^{\circ}$ - $25^{\circ}$  NE.; and the Opalite strike-slip fault, trending N.  $52^{\circ}$  E. and dipping  $80^{\circ}$ - $90^{\circ}$  NW. The greater part of the ore taken from the mines to date has been removed from the Barnum fault zone.

The sequence of events in the area, after deposition of the sediments, appears to have been:

(1) *Emplacement of the igneous rocks, with resulting arching or depressing of the sediments adjacent to laccolithic and lopolithic bodies.* During a late stage in their consolidation the marginal parts of some of the intrusive bodies were altered to a soft, whitish, kaolinitic material. The alteration was probably effected by some kind of deuteric process<sup>①</sup>, and is not related to the mercury mineralization.

(2) *Deformation, including folding and faulting.* The Barnum (normal) fault is cut by, and is hence older than, the Black Wall thrust. It seems probable that the Black Wall thrust and certain strike-slip faults (as the Opalite) were formed during the same period of regional compression which produced the fold structures in the sediments. If so, the high-angle normal faults predate the folding; the Barnum fault, for example, may originally have been a vertical fault, rotated into its present orientation when the folding occurred.

(3) *Mineralization, effected by solutions rising along the fault planes and accompanied by intense hydrothermal alteration.* The mineralization is probably related to emplacement of igneous bodies which did not reach the surface in this district.

The significance of this history is that:

(1) The present structural arrangement is premineral. Sandstone and shale beds, inclined in various directions, cut by faults (of at least two generations) which carry open-textured breccia or dense gouge, or both, provided a complex pattern of intersecting permeable and impermeable layers and sheets which controlled the upward movement of the mineralizing solutions, and hence controlled the localization of the mineral deposits. The geologic problem therefore consists essentially of working out the manner in which the ascending solutions were guided by planes of differing degrees of permeability. As there has been little or no postmineral

<sup>①</sup> Goodspeed, G. E. Calcite-bearing diabase near Morton, Washington. (abstract): Geol. Soc. Am. Bull. vol. 42, pp. 189-190, 1931.



deformation, the problem of the displacement of ore bodies by faulting does not occur in those parts of the mine workings examined in the course of this survey.

(2) As the observed intrusive igneous rocks in the mine workings predate, and are not genetically related to the mercury ores, the occurrence of igneous bodies and of deuteric-alteration effects associated with them has no bearing on the localization of mineral deposits.

#### DESCRIPTION OF WORKINGS

##### GENERAL STATEMENT

Geologic relations in the Roy—B.-M. mines are shown by appropriate symbols on the accompanying map and sections (pl. 2). The following description proceeds, in general, from the haulage tunnels and the lowest workings along the Barnum ore body in both mines to the highest levels, where the Barnum fault is displaced by the Black Wall thrust; as progressively younger beds are encountered from level to level, the stratigraphy of the sedimentary rocks is adopted as a framework for the discussion. For convenience in reference, the sediments are grouped into five lithologic units, which are from the base upward—(1) the Haulage siltstone, (2) the Lower Massive sandstone, (3) the Roy sandstone-shale, (4) the Barnum sandstone, and (5) the Nigger Heaven shale. Two large igneous bodies are—(1) the Haulage 'laccolith' and (2) the B.-M. No. 4 'lopolith', the former occurring at the base of the sedimentary sequence listed above, and the latter as an intrusive into the Roy sandstone-shale unit. Sandstones and shales that show through gaps in the lagging near the portal of the B.-M. haulage tunnel underlie the Haulage laccolith and are so indicated on the map, but these beds do not otherwise enter into the geology of the mine area and are not included in the stratigraphic column.

The only sediments of any direct economic interest are the Lower Massive sandstone unit and a massive sandstone member of the Barnum sandstone unit. The intervening sedimentary units must be described, as correlation of the possible productive beds from place to place in the mine workings depends in part on the position of these beds in the sequence as a whole; however, the reader who is interested primarily in mineralization may elect to pass over rapidly or omit altogether the descriptions of the Haulage siltstone, the Roy sandstone-shale unit, and the Barnum sandstone unit.

##### THE HAULAGE SILTSTONE UNIT

The Haulage siltstone is a sequence of massive gray siltstone, black shale beds, and some thin sandstone layers, having an aggregate thickness of about 200 feet. It is exposed in the Roy No. 1 haulage tunnel and the B.-M. haulage tunnel, overlying a thick diabasic intrusive body (the Haulage laccolith) in both. Plate 2,

section A-A, shows the relations between individual beds making up the Haulage siltstone and the difference in the location of their exposures in the two tunnels resulting from a change in strike, the general easterly dip of the sediments, and a 100-foot difference in the levels of the tunnels. Correlation is based on two key beds—(1) a dark-gray to black, carbonaceous shale with distinctive coal seamlets which occurs at station 48 plus 175 feet in the Roy tunnel and at station 8 plus 700 feet in the B.-M. tunnel; and (2) a 2-foot coal bed which occurs at station 50 plus 10 feet in the Roy tunnel, in the hanging wall of the Barnum fault at station 79 in the B.-M. No. 6 drift, and at station 77 plus 325 feet in the B.-M. No. 6 tunnel. A massive gray siltstone, from 70 to 80 feet in thickness, overlies the coal bed in both tunnels and forms the uppermost member of the Haulage unit. Change in thickness and/or lithology of individual beds between the two tunnels, and failure of certain thin sandstone beds to match (see pl. 2), are probably due to lateral gradation and lensing, which characterizes all the sediments in the mine workings. Another feature which complicates correlation is exemplified by the fact that the black shale and coal seamlets (Key Bed No. 1) *overlie* a minor sill in the B.-M. tunnel and *underlie* a minor sill in the Roy tunnel, indicating that the sill crosses the bedding between the tunnels or that there are two small sills, one in each tunnel section.

The Barnum fault causes a repetition of the upper massive siltstone member of the Haulage siltstone unit at or near the junction of the Roy No. 1 (haulage) tunnel and drift and also at or near the B.-M. No. 6 (haulage) tunnel and drift. (It should be noted that the Roy drifts are numbered from the bottom up, and the B.-M. drifts from the top down.)

#### GENERAL FEATURES OF THE BARNUM FAULT

The Barnum fault has been explored by drifts and raises for about 1,300 feet along the strike and through a vertical range of about 350 feet. The curves and somewhat angular bends of the drifts, as seen on the map, reflect local changes in strike and indicate that the fault plane is a fluted surface. Where the fault is not plotted on the map, it usually intersects the level of the drift floors at or near the base of the west sides. The dip averages 50° westward, but varies from 35° to 60°. Movement appears to have been chiefly dip-slip and is normal, the displacement varying from 35 to 50 feet in different parts of the mine workings. The thickness of the brecciated zone ranges from a few inches to 3 feet or more; averaging about 1 foot. The hanging wall is usually remarkably smooth, often carrying a thin sheet of clayey gouge; the footwall is usually less sharply defined.

Films, seams, and disseminated particles of cinnabar can be found in the fault breccia in nearly all parts of the mine workings, but the showings vary from place to place. There is no consistent and conspicuous relationship between values and (1) changes in strike or dip of the fault, or (2) changes in the lithology of the hanging-wall or footwall blocks. It is possible that a detailed assay map of the workings would show a correlation between mineralization in the breccia and (1) or (2) or both.

The breccia has been largely mined out in the B.-M. workings and in the southern part of the Roy workings. Decrease in the size of the stopes in a northerly direction in the Roy workings and relatively poor showings of cinnabar in the breccia in the vicinity of the north headings of the Roy drifts suggest that values decrease toward the north. Structural complications at the south headings of some of the B.-M. drifts, and the question of the southerly continuation of the Barnum fault, will be discussed in a later section (see p. 29). Quantitative statements with regard to the general distribution of values along the trend of the fault and, what is equally important, at different levels in the workings, could be based only on an assay map.

#### THE LOWER MASSIVE SANDSTONE UNIT

The Haulage siltstone unit is overlain by a medium-coarse light-gray massive micaceous sandstone from 40 to 50 feet in thickness. The contact between the sandstone and the Haulage siltstone is 87 feet west of the junction of the Roy haulage tunnel and the Roy No. 1 drift on the Barnum fault (station 51). It forms both the hanging-wall and footwall sides of the Roy No. 1 drift north of the junction except for the northernmost 90 feet, where the basal part of the overlying Roy sandstone unit comes down to the drift level in the hanging wall. The basal contact is exposed in the lower part of the footwall side in the Roy No. 1 drift about 100 feet south of the junction. The top of the sandstone appears in both hanging-wall and footwall blocks in a raise (above station 51) between the Roy No. 1 and Roy No. 2 levels, indicating that the displacement on the Barnum fault is here about 32 feet (pl. 2, section B-B).

These relations—namely, an extension of drifts north and south along a well-defined crush zone on the Barnum fault—are repeated at all the other T-shaped junctions of crosscut tunnels and drifts in the Roy—B.-M. workings except in the B.-M. No. 6 (haulage tunnel) level. Here, at station 78, there is no simple west-dipping Barnum fault; the shale-siltstone bedding extends across the roof at the junction and is cut by two or more curving and intersecting faults about 5 feet east of the station, in the entry of a short blind adit which continues the trend of the haulage tunnel beyond the

junction. An interpretation of the failure of the Barnum fault to be normally developed at this point is suggested below.

The drift north of the junction is largely lagged for 120 feet, to station 79. At and near this station the Barnum fault is in the east side of the drift; a coal bed in the hanging-wall block lies on strike with, and is probably the same as, the coal bed which occurs in the haulage tunnel 95 feet west of station 78 (Haulage siltstone Key Bed No. 2; see map).

Approximately 25 feet north of the junction (station 78) a raise connects this drift with the B.-M. No. 5 level. The first 20 feet of the raise above the B.-M. No. 6 level follows a typical crushed zone of the Barnum fault; this fact leads to the inference that the B.-M. No. 6 drift was driven along the Barnum fault from this point northward to station 79, where the fault appears in the east side. At the 20-foot point in the raise the Barnum fault appears to be displaced upward and westward by a thrust fault; as shown in section C-C, the raise is in the footwall block with reference to the Barnum fault for some distance beyond, reentering the fault zone just below the B.-M. No. 5 level. Relations in the section indicate that movement on the thrust fault is probably less than 25 feet.

The drift south of station 78 is lagged for 35 feet, to a place where a short adit extends eastward from it. The south side of the adit and a caved portion of the roof of the drift just to the south show a cross fault trending N.  $58^{\circ}$  E. and dipping  $45^{\circ}$  NW. In the highest part of the caved portion of the drift, north of this cross fault, brecciation and a drag effect in sheared bedding suggest the presence of the Barnum fault, but the exposure is too small and local relations are too complex to permit certain identification.

The diagrammatic and hypothetical sketch sections of figure 2 illustrate an interpretation of the relations described above—that is, north of the cross fault. 'A' shows the Barnum fault in the east side of the tunnel at station 79; 'B' is the section in the raise where the Barnum fault is displaced by a thrust; 'C' is the section at the junction where the simple Barnum fault does not occur, although a distorted (dragged) part of it and/or its breccia may appear; and 'D' is a section 35 feet south of the junction, where the fault does not show in the drift but may have been exposed by the caved portion of the roof. The essence of the theory illustrated by these sections is that the thrust fault, dipping generally eastward, has a southerly component of dip which causes it to appear at progressively lower levels from north to south. This theory fits observed relationships, and it is strengthened by the fact that it is precisely what would occur if the thrust were parallel to the bedding of the sediments, which dip to the southeast; similar bedding thrusts occur elsewhere in the mine workings. If the theory is correct, it appears that the B.-M. haulage tunnel just happened, by



unfortunate mischance, to approach and cross the usual position of the Barnum fault (at this level) where the fault was cut out by the thrust; had the haulage tunnel been located a short distance either to the north or to the south it would have cut the Barnum fault, either in the hanging-wall or footwall block of the

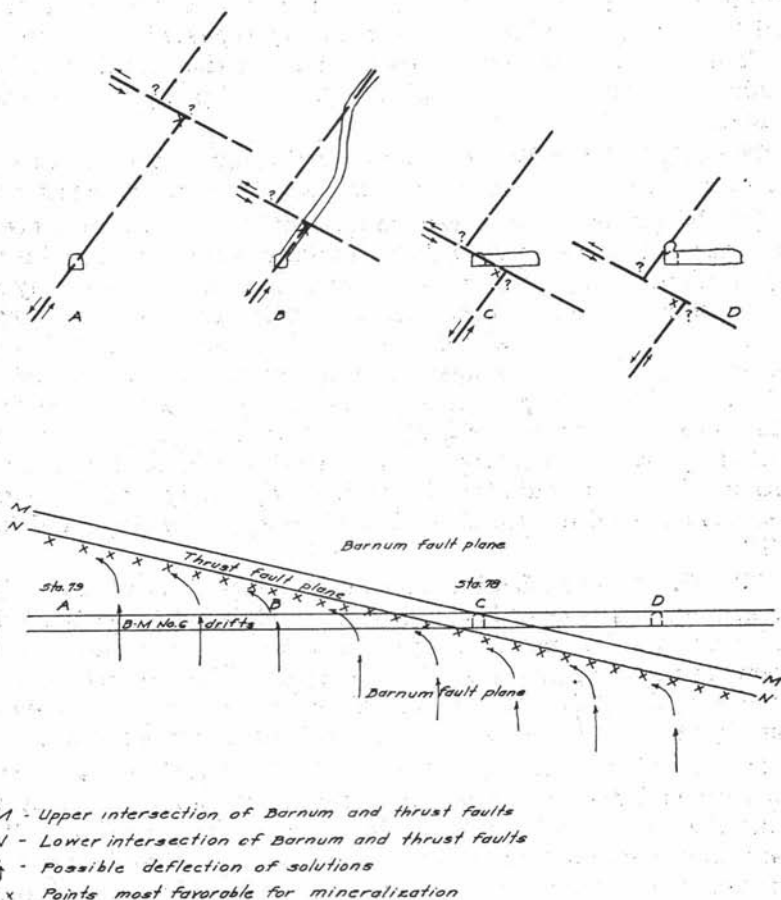


Figure 2. Diagrammatic sections to illustrate theory of displacement of the Barnum fault in B-M. No. 6 level. No scale.

thrust fault. The blind adits shown in 'C' and 'D' (and in pl. 2) were probably driven in a search for the Barnum fault.

The displacement on the Barnum fault in this vicinity (neglecting displacement on the thrust, which cancels out if the thrust is parallel with the bedding and is small in any case) can be determined by the offset of the coal bed that occurs in the hanging-wall block at station 79 and is (probably) repeated in the footwall block in the adit 35 feet south of the junction (station 78). A graphic solution of the problem gives a dip-slip movement of 45 feet.

The offset of the Barnum fault by the minor thrust fault may have some economic significance in two different connections:

(1) Displacement of the Barnum fault may have interfered, to a greater or lesser extent, with the upward movement of mineralizing solutions along the Barnum breccia zone, and, hence, may have caused emplacement of better-than-normal values wherever movement of the solutions was concentrated. The principles involved are discussed fully in connection with the Black Wall thrust (see p. 18). If the same principles apply in this case the most favorable conditions for concentration of flow occur at the places indicated by crosses in figure 2. Whether there is an actual concentration of values could be determined by study of the Barnum breccia in the raise, as indicated in plate 2, section C-C, and figure 2, 'B'.

(2) The Lower Massive sandstone shows disseminated cinnabar in the hanging-wall block near station 51 in the Roy No. 1 drift. The sandstone has not been mined, as the reported values (up to 9 pounds per ton) are lower than those in the breccia along the Barnum fault. What the actual values are, and how far they continue in the sandstone away from the fault, are not known.

The cinnabar in the sandstone in the Roy workings was doubtless formed by solutions which entered into and moved upward along the sandstone bed from the Barnum breccia zone. It appears that pervious sandstone in the hanging-wall block of the Barnum fault, where the attitude of the bedding would permit passage of solutions *up the dip* of any pervious layer, would be decidedly favored for mineralization over the same sandstone in the footwall block. As noted above, the showings of cinnabar in the Lower Massive sandstone in the Roy workings are in the hanging-wall block. Section C-C indicates that the sandstone now exposed in the B.-M. workings happens to lie in the footwall block; it is present, though not exposed, in the hanging-wall block. If future development of the B.-M. mine or of both mines depends on the blocking out of a large tonnage of low-grade (sandstone) ore, and if the Lower Massive in the Roy workings proves to be worth

mining, the possibility that the same bed carries values could be investigated by a short raise from the B.-M. No. 6 drift.

South of the cross fault mentioned earlier (35-40 feet south of station 78 in B.-M. No. 6) sheared and distorted bedding strikes N. 70°-80° W. and shows variable high dips. The bedding north of the cross fault strikes N. 25°-30° E. This is the only case of a marked change in strike direction on two sides of a fault observed in the Roy-B.-M. properties. The most probable explanation is that it represents drag on a fault, but the exposure is too limited to permit working out of the problem. The zone of disturbance is in rough alignment with splits of the Barnum fault at the south ends of the B.-M. No. 3 and B.-M. No. 4 drifts (pl. 2), and may be related to an abrupt change in the trend of the Barnum fault, to be discussed later (see p. 29). The fact that the drift was not extended in the disturbed zone suggests that values were low or altogether absent.

Some interest attaches to whether the Barnum fault (whatever its trend) is mineralized south of the B.-M. No. 6 haulage tunnel, the reason being that B.-M. No. 6 is the lowest level in which the fault is exposed. Attempts to locate the fault south of the haulage tunnel by drifting along its usual trend, and by cross-cutting to the east, failed to discover it. If the theory outlined above is correct, the fault lies a short distance west of the B.-M. drift south of the haulage tunnel, and can be reached by a short crosscut to the west (fig. 2, 'D').

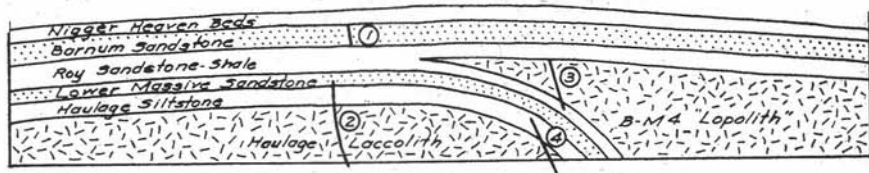
#### THE ROY SANDSTONE-SHALE UNIT

The Roy stratigraphic unit, which overlies the Lower Massive sandstone, is 120-130 feet thick. The lower member is dark-gray banded siltstone interbedded with fine light-gray sandstone that contains numerous carbonaceous seams; it grades upward in the middle of the unit into fine massive light-gray sandstone that also contains some carbonaceous seams. The upper 45-50 feet of the unit is dark-gray to black massive shale. The unit contains two coal beds, one about 10 feet from the base (Roy 'A' coal) and one about 45 feet from the top, near the base of the upper shale member (Roy 'B' coal). The most complete section of the unit is seen in the raise from B.-M. No. 5 to B.-M. No. 4 (section C-C).

The basal dark siltstone and sandstone member, and the Roy 'A' coal, make up the hanging wall of the Barnum fault in the northern part of the Roy No. 1 drift. The Roy 'B' coal appears in the hanging wall of the fault in the vicinity of the small fork in the Roy No. 2 drift above station 51 on the Roy No. 1 level. A coal bed, probably the Roy 'B', appears in the footwall of the Barnum fault in the east side of the B.-M. No. 4 drift at station 69, the relations being shown in section C-C. (It will be noted on the mine map that the B.-M. No. 4 drift is a continuation of the Roy No. 2 drift at

the same level.) The Roy No. 2 drift is therefore cut largely in the various members of the Roy sandstone-shale unit, but the southern part of it is partly lagged or caved and details of lithologic changes were not recorded in the first traverse. Since the Roy stratigraphic unit, as such, has no direct economic significance, no return to this drift for detailed study of the sediments seemed justified, and the rock types are not plotted on the map.

The rock exposed in the B.-M. No. 4 tunnel is fresh black diabase, altered to soft whitish material along shear zones. The tunnel is lagged for approximately 100 feet from the portal; rubble behind the lagging corresponds closely in lithology with the lower banded dark- and light-colored siltstone and sandstone of the Roy unit, suggesting that the lower part of this unit makes the floor of the intrusive. A well-defined contact between a soft whitish porphyritic rock, definitely part of the intrusive body, and a soft whitish non-porphyritic material occurs near the end of the 40-foot blind cross-



The numbered lines indicate parts of sedimentary-igneous sequence penetrated by representative crosscut tunnels: (1) Roy No. 3; (2) Roy No. 1; (3) B.-M. No. 4; and (4) B.-M. No. 6.

Figure 3 Sketch section to illustrate inferred relations of the Haulage 'Laccolith' and the B.-M. No. 4 'Lopolith'.

cut that continues along the trend of the B.-M. No. 4 tunnel past its junction with the B.-M. No. 4 drift (station 63). It is uncertain whether the nonporphyritic material is (1) part of the intrusive, or (2) the middle light-gray sandstone member of the Roy unit, now altered beyond (megascopic) recognition. Similar soft whitish rock, irregularly interbedded with or cut by altered porphyry, makes up both walls of the B.-M. drift south of the junction (station 63). North of the junction the altered complex makes up the footwall of the B.-M. drift to station 67, and the hanging wall to station 69. In the raise from B.-M. No. 4 to B.-M. No. 3, 40 feet south of the junction, the whitish altered rock is overlain by the upper black shale member of the Roy unit, the contact occurring about 60 feet above the B.-M. No. 4 drift in the hanging wall and 110 feet above the drift in the footwall (section D-D).

If the whitish nonporphyritic material in the blind extension of the B.-M. No. 4 tunnel is altered sandstone, the igneous body is 75



feet or more in thickness. If all the whitish material up to the level of the black shale mentioned above is igneous, the body is 135 feet or more in thickness. In either case, if the body maintained its thickness in a northerly direction along the strike of the enclosing beds, it would be cut by the raise from B.-M. No. 5, which enters the B.-M. No. 4 drift at station 69, 200 feet north of the B.-M. No. 4 crosscut tunnel (section C-C). The fact that only 10 feet of porphyry appears in the section in this raise indicates that the igneous body thins rapidly. As the overlying sediments show the prevailing north strike, and the underlying beds, especially as seen in the B.-M. haulage tunnel, diverge sharply to the west, it appears that the emplacement of the B.-M. No. 4 igneous body may have been accommodated by a relative down-bending of the underlying beds—that is, that the body is probably lopolithic, rather than sill-like or laccolithic. Figure 3 shows the relations between the Barnum lopolith and the Haulage laccolith, and suggests that local departures of bedding from the prevailing north strike in the mine area as a whole may be due to distortion resulting from intrusion of the igneous units. In so far as arches and sags in the east-dipping beds bear on localization of flow of upward-moving solutions, this generalization may be significant in the search for ore bodies.

#### THE BARNUM SANDSTONE AND THE NIGGER HEAVEN BEDS

The lower 10-15 feet of the Barnum unit is a fine- to medium-grained light-gray sandstone, which grades upward into a strikingly banded stratum, about 15 feet in thickness. This 'Ribbon member' consists of interlaminated black and light-gray to white sandstone and siltstone, the laminae varying from a fraction of an inch to several inches in thickness; a distinctive feature is the presence of tube-like structures, probably animal borings now filled with white sand. The Ribbon member is overlain by a succession of layers of white to black sandstone and siltstone, the beds varying from a few inches to several feet in thickness, and including some ribbon beds. The proportion of sandstone increases upward, and the uppermost member is a coarse massive tuffaceous sandstone, from 13 to 15 feet in thickness. This bed, hereafter referred to as the 'Paradise member', is overlain by black sandstones, siltstones, and shales of the Nigger Heaven stratigraphic unit. The overall thickness of the Barnum unit to the top of the Paradise member is approximately 150 feet; the thickness of the Nigger Heaven shales is not known, as the top is not exposed in the mine workings.

The most complete section of the unit is seen in the B.-M. No. 3 tunnel and the raise from B.-M. No. 3 to B.-M. No. 2 (section D-D). The lower fine light-gray sandstone is exposed about 70 feet from the portal of the B.-M. No. 3 crosscut, the base being hidden by lagging which is continuous from the portal to this point. The

sandstone grades upward into the Ribbon member at station 18 plus 125 feet, and the dark and light sandstones and siltstones described above appear at the junction of the tunnel and the B.-M. No. 3 drift. The middle parts of the unit are exposed in the raise from B.-M. No. 3 to B.-M. No. 2 (just north of station 56 in B.-M. No. 3), and the upper massive sandstone phase makes up the greater part of the walls of the B.-M. No. 2 tunnel. The base of the overlying Nigger Heaven shale is exposed in the upper part of the caved heading of the B.-M. No. 2 tunnel.

Essentially the same sequence is repeated in the Roy No. 3 tunnel and drifts. The basal light sandstone occurs about 70 feet from the portal. It is overlain by the distinctive Ribbon member, being separated from it here by a porphyry sill. As shown on the map (pl. 2), a divergence between the strike of the beds and the trend of the Barnum fault means that progressively younger beds are encountered northward along the Roy No. 3 drift; the upper coarse massive sandstone phase, not necessarily including the uppermost Paradise member, occurs in the hanging wall at the heading. The total aggregate thickness of the unit in the Roy No. 3 crosscut and drift is approximately 250 feet as compared with 150 feet in the Barnum workings; the difference is due to the presence of a number of small sills in the Roy workings.

#### THE PROBLEM OF THE BLACK WALL THRUST

##### GENERAL STATEMENT

According to local reports, the richest ore found in the Roy—B.-M. mines was taken from two adjoining stopes known to the miners as "Paradise" and "Nigger Heaven", both of which are inaccessible at the present time. Even after these reports are properly discounted it is evident that the Paradise-Nigger Heaven lode was exceptionally rich ground (for the Morton district), and that an understanding of conditions which controlled its formation may serve as a guide in the search for similar bodies elsewhere in the area. The problem might be relatively simple if the workings were open for study, but, under the present conditions, only indirect evidence can be brought to bear on it. It will make for clarity in discussion if the *reported* relations in those parts of the mine workings not now accessible are separated from relationships now observable in adjacent parts of the mine.

It is reported that the ore was encountered in raises driven upward along the Barnum fault from the Roy No. 3 level south of the junction of the Roy No. 3 drift and crosscut tunnel. However, in contrast with the steep westerly dip of the Barnum ore body (along the Barnum fault), the Paradise-Nigger Heaven ore body extended upward to the west at a low angle of slope (clearly along the bedding of east-dipping sediments in what may be provisionally re-

garded as the hanging-wall block of the Barnum fault). A large raise (timber chute or ore chute?) known as the "Grand Canyon" (pl. 2) was one of the connections between the Paradise-Nigger Heaven workings and the Roy No. 3 level. The ore consisted of streaks and disseminations of cinnabar in generally undisturbed rock, in contrast to the brecciated condition which characterizes the Barnum ore body. In Nigger Heaven the values occurred in dark-gray or black siltstone or sandstone, always under a well-defined and continuous layer of dense black plastic clay, ranging from a few inches to more than a foot in thickness, known as the "Black Wall". There were no values above the sheet of clay, and the Barnum-type breccia ore seemed to terminate abruptly at the lower contact of the sheet. The Black Wall clay and the associated dark ores of the Nigger Heaven area terminated in the vicinity of the Grand Canyon. South of the Grand Canyon and at the same general level, the values occurred in white sandstone, the white sandstone stope being known as "Paradise." Both stopes were "large" (the mined out thickness in the Paradise stope is as much as 15 feet), and the Paradise ore was said to contain up to 50 pounds of mercury to the ton. All those reported relations (except the tenor of the ore) are of such nature as to be apparent to the miners from whom the information was obtained, and are probably credible.

#### RELATIONS NORTH OF THE PARADISE-NIGGER HEAVEN AREA

Several raises ascend from the Roy No. 3 drift, north of the crosscut tunnel, to short drifts just under the Black Wall. (The identity of the Black Wall in these drifts with the Black Wall reported in the Paradise-Nigger Heaven area is established by the fact that one of these drifts shows old crushed timbers of a drift—now caved—which followed the Black Wall northward from the Nigger Heaven.) In the second raise south of the Roy No. 3 heading (fig. 4, sections M-M, N-N) the Barnum fault terminates against the Black Wall, which is here seen to be a sheet of clayey gouge along a fault plane that is essentially parallel with the bedding of east-dipping carbonaceous shales. Drag on the fault indicates that it is an over-thrust which truncates the Barnum fault and displaces it an unknown distance upward to the west. A coarse white sandstone bed, undoubtedly the uppermost sandstone member of the Barnum unit, occurs in the footwall of the Barnum fault from 10 to 15 feet below the level of the Black Wall thrust, and the carbonaceous shales in which the thrust lies are probably correlative with the black shales which overlie the Barnum sandstone in the B.-M. No. 2 tunnel, as described earlier. Essentially the same relations are seen in the next accessible raise, 250 feet to the south (fig. 4, section 0-0). Here the Black Wall thrust and the associated stratigraphic members are much higher above the Roy No. 3 level

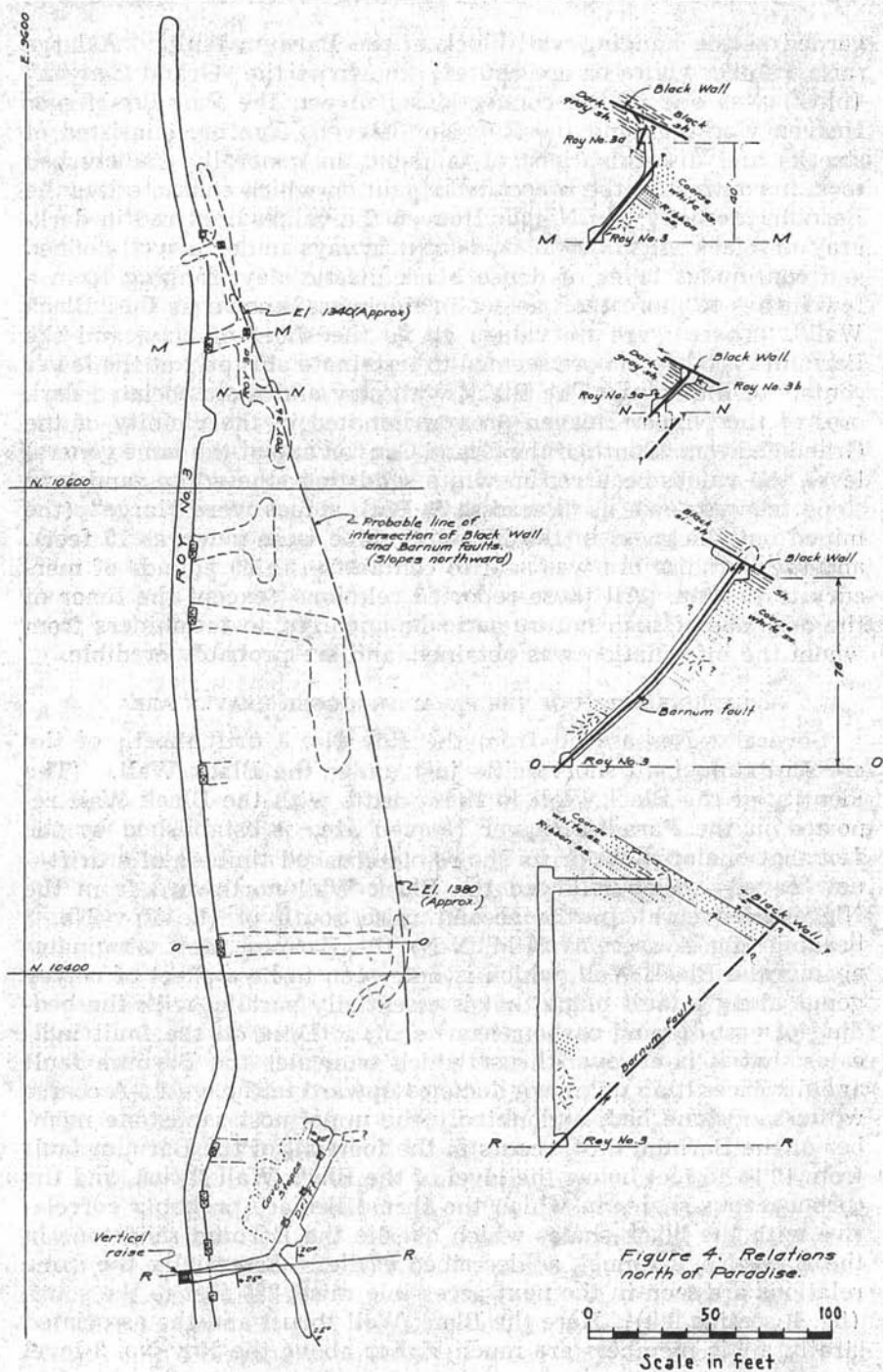


Figure 4. Relations north of Paradise.

0 50 100  
Scale in feet



than in the raise last mentioned, the southerly increase in height being due to a divergence between the trend of the Roy No. 3 drift and the strike of the beds. Dark shales and siltstones just below the Black Wall in both raises show some cinnabar colors, but the values are said to be very much lower than those encountered in the Paradise-Nigger Heaven stopes.

#### RELATIONS SOUTH OF THE PARADISE-NIGGER HEAVEN AREA

The second raise on the Barnum fault south of the Grand Canyon gives access to a stope in a white sandstone bed south of, and reportedly a short distance below the level of, the old Paradise workings. As most of the mining was done by Jack Rosborough, this area is called "Jack's sandstone stope" in the discussion to follow. (Because of a confusion of lines indicating extensive caved workings in this vicinity on the general map, and because of the need for constant reference, this part of the mine map is reproduced as figure 5.) The position of the sandstone, its lithology, and the lithology and sequence of the underlying beds (as seen in the raise on the Barnum fault) indicate that it is probably the uppermost massive sandstone member of the Barnum unit. The stope extends about 30 feet up the dip of the sandstone (westward) from its intersection with the Barnum fault—that is, the stoped-out area is in the hanging-wall block (fig. 5, section T-T). The sandstone, which is about 13 feet in thickness, carries disseminated cinnabar.

In the Roy No. 4 tunnel a dark banded sandstone is overlain by a coarse massive light-gray sandstone just within the portal. At a place 60 feet from the portal the sandstone bed is overlain by dark-gray to black carbonaceous shales and siltstones. A raise 20 feet north of the junction of the Roy No. 4 tunnel and drift lies in a typical Barnum crush zone to about 25 feet above the Roy No. 4 drift; white sandstone appears in the footwall. The fault does not continue upward to the east beyond the 25-foot point, and seems to be displaced by an east-dipping thrust, but a short raise along the dragged Barnum breccia on the thrust plane failed to reenter the Barnum fault. A raise 30 feet south of the junction exposes essentially the same relations; it follows the Barnum crush zone to the 25- to 30-foot point, shows sandstone in the footwall, and shows a displacement of the Barnum fault by an east-dipping thrust. In this case, however, a raise along the thrust plane does reenter the Barnum crush zone, the displacement on the thrust being about 10 feet (fig. 5, section T-T). Drifts extend along the Barnum fault about 15 feet north of the top of the raise and about 40 feet to the south; the southern drift encountered glacial till at the heading.

The occurrence of the white sandstone bed in the Roy No. 4 crosscut, in the hanging wall of the Barnum fault, and in the raises in the footwall of the fault, was interpreted at the time of examina-

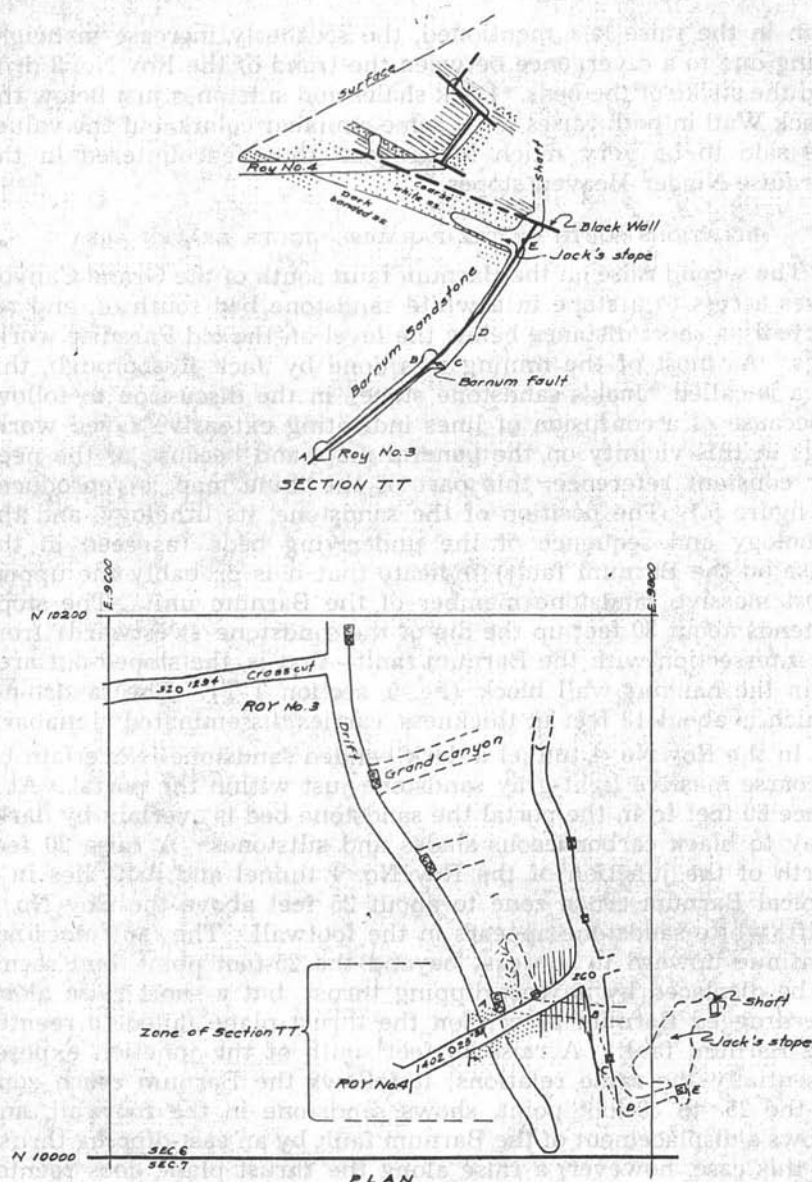
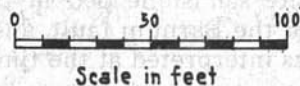


Figure 5. Relations south of Paradise.



tion as being the result of the usual repetition of the eastward-dipping bedding by dip-slip movement on the Barnum fault—as, indeed, it is. However, it was not until the relations in the Roy No. 4 workings were plotted and projected into the same vertical section as the relations in Jack's sandstone stope, above the Roy No. 3 workings, that the possibility of a relatively large displacement of the Barnum fault between the two areas revealed itself (fig. 5, section T-T). Certain points bearing on this proposition were checked in the course of a second visit to the mine workings in company with Mr. John Mullen. The most significant are: (1) the identity of the sandstone in the Roy No. 4 tunnel with the sandstone in Jack's stope, and the absence of displacement of this bed between these two areas (fig. 5, section T-T), indicating that the Barnum fault observed in the Roy No. 4 workings does not extend downward so as to cut the sandstone; and (2) the presence of a bedding thrust in the shales above the sandstone in the Roy No. 4 tunnel. It seems probable that this thrust, with a displacement of 40-45 feet, and possibly the minor thrust (displacement 10-12 feet) which cuts the Barnum fault in the Roy No. 4 raises, represent a southerly continuation of the Black Wall thrust fault. While there are alternative possibilities, this view has sufficient support to justify its adoption as a working hypothesis.

#### PROBABLE STRUCTURAL RELATIONS IN THE PARADISE-NIGGER HEAVEN AREA

The structure sections of figure 6 illustrate the consequences of the hypothesis mentioned above: 'A' shows the relations north of the Paradise-Nigger Heaven workings, where the Black Wall thrust is *above* the uppermost massive sandstone of the Barnum unit in the *footwall* of the Barnum fault; 'C' shows the relations south of the Paradise-Nigger Heaven workings, where the Black Wall thrust is *below* the uppermost massive sandstone member of the Barnum unit in the *footwall* of the Barnum fault.

These relations indicate that at some place between the sections A and C the thrust fault must pass through or lie in the massive sandstone in the footwall of the Barnum fault (section B). It is probable that the development of the fault in the massive sandstone would be notably different from its development in the bedded shales; the most important difference, from the point of view of the present discussion, being that the dense, impervious gouge of the Black Wall type would not have been formed.

#### ORIGIN OF THE PARADISE-NIGGER HEAVEN ORE BODY

The implications of this structural arrangement with regard to the origin of the Paradise-Nigger Heaven ore body depend entirely on the orientation of intersecting planes and layers of varying permeability, including sedimentary beds, fault breccia, and fault

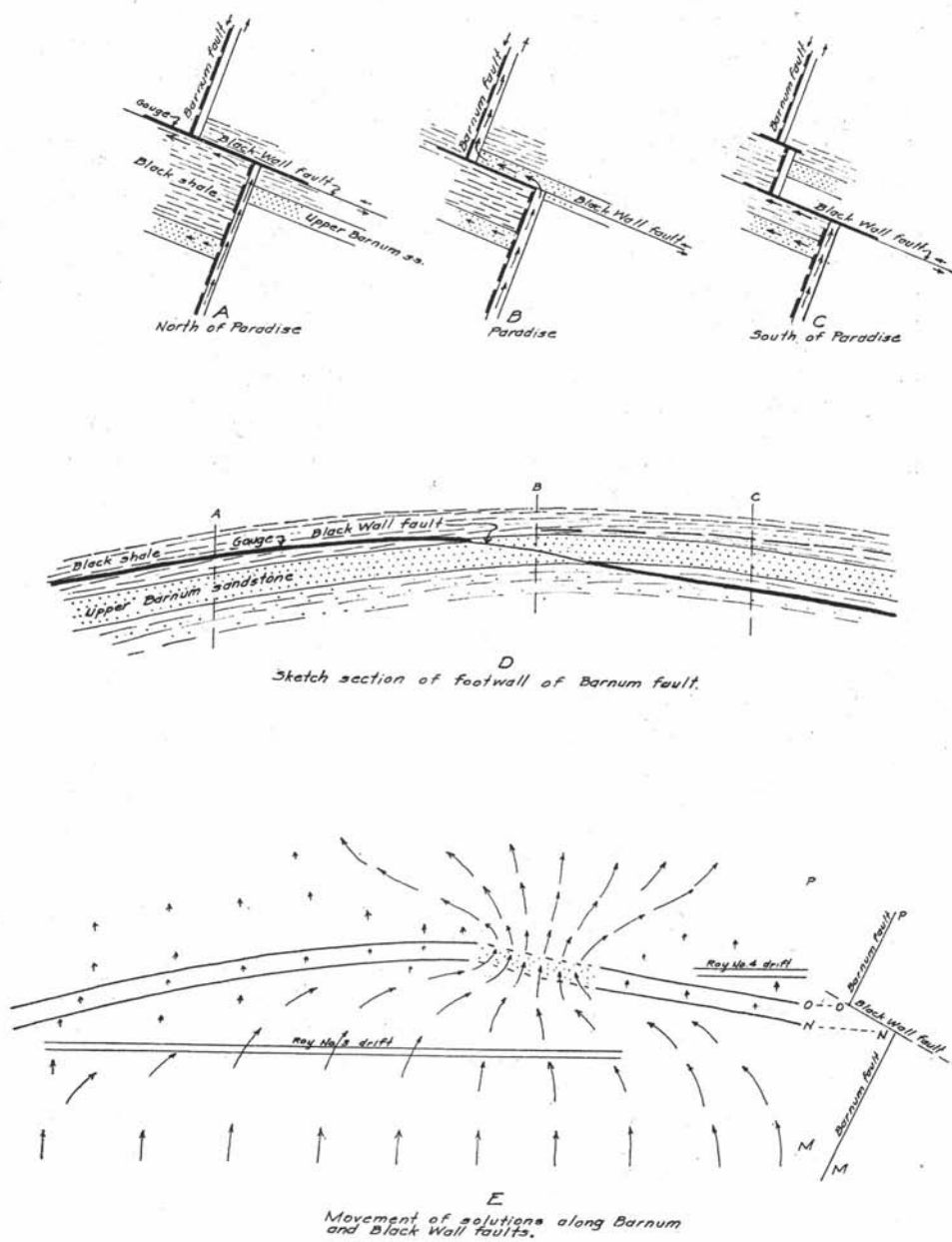


Figure 6. Theory of origin of the Paradise-Nigger Heaven ore body

gouge. Other things being equal, the mineralization will be determined by the rate of upward flow of solutions to, through, and away from any area where conditions are favorable for the precipitation of their mercury content.

In the lower mine workings the best values occur in the Barnum fault breccia, indicating that the strongest flow of the ascending solutions was localized along this plane (fig. 6, sections A, B, C). Some "leakage" into pervious sandstones of the hanging-wall block undoubtedly occurred; but under normal conditions the main flow of solutions continued upward in the Barnum breccia, partly because it was more pervious than the sandstone members of the sedimentary sequence and possibly, in part, because of the presence of a thin sheet of gouge on the remarkably smooth hanging wall of the Barnum fault, tending to prevent escape into the pervious hanging-wall sandstones. The absence of the gouge on the footwall is of no consequence, as the attitude of the bedding does not favor movement of solutions from the fault into the footwall sandstones.

Wherever the Black Wall type of clayey gouge was developed along the Black Wall thrust, that material provided a perfect dam for solutions rising along the Barnum fault (fig. 6, section A). Such solutions as passed up the dip of the Barnum fault to the Black Wall were forced to continue their upward movement along the bedding of whatever rocks happened to be beneath the Black Wall gouge, so that even relatively impervious shales and siltstones were mineralized and do, in fact, show cinnabar colors immediately beneath the gouge (in the drifts north of the Paradise-Nigger Heaven area, as described above). It is to be expected that such movements would be relatively slow, and that, as suggested by arrows in figure 6, section E, there would be a lateral deflection of currents toward any breach in the Black Wall gouge, as where, in the Paradise-Nigger Heaven area, the thrust fault was developed in sandstone. The high values reported from the sandstone in this area are believed to be the result of this concentration of flow. Shearing and fracturing of the sandstone in the vicinity of the thrust might have been a contributing factor by increasing its permeability, but it is not necessary to postulate that the sandstone at the breach was more pervious than elsewhere; the point is that it was notably *less impervious* than the Black Wall gouge, and more readily entered by solutions rising along the Barnum fault breccia where it overlies the truncated edge of that fault than where it occurs in the hanging wall of the fault. The concentration of flow might have been accentuated, in this instance, by reason of the breach occurring near the top of a broad arch in the Black Wall thrust plane, but a consideration of the hydraulic principles involved indicates that it was not dependent on this factor.

How far below the level of the Black Wall thrust the deflection toward the breach would significantly affect rates of flow in the



Barnum fault breccia is, of course, uncertain (fig. 6, section E). The facts that, in general, the stopes are larger and present showings of cinnabar are better in the southern part of the Roy property (that is, in the general area below the breach) suggest that the effect of the breach may have extended several hundred feet below the level of the Black Wall. A good assay map of the mine workings would be required to test this proposition.

As indicated in section B (fig. 6), it is to be expected that solutions moving upward along the bedding in the Paradise-Nigger Heaven area should reenter and continue upward along the (displaced) Barnum fault. This inference is strongly supported by a statement, made by a miner who worked in Paradise, that the Paradise stope followed rich sandstone ore upward to a smooth wall, beyond which no values were found. The wall is, according to the interpretation advanced here, the hanging wall of the Barnum fault (fig. 6, section B); whether the values and/or the workings continued upward in the Barnum breccia is not known. It is to be expected that the flow lines would fan out laterally along the fault above the breach in somewhat the same manner in which they converged on the breach from beneath (fig. 6, section E). Distribution of values in the Barnum fault breccia above the Black Wall thrust would depend on this factor, and, of course, on the cinnabar content of the solutions that reached this level. In any event, good values should *not* be expected along the Barnum fault above the Black Wall north or south of the Paradise-Nigger Heaven breach, for reasons shown in the section. This inference receives some support from the fact that showings of cinnabar are poor, and reported values low, in the segment of the Barnum fault penetrated by the Roy No. 4 workings (fig. 6, section E).

TYPES OF STRUCTURAL RELATIONS FAVORABLE FOR MINERALIZATION  
ELSEWHERE ALONG THE BLACK WALL THRUST

The essential requirement for the formation of the Paradise-Nigger Heaven type of ore body is a breach in impervious gouge along the Black Wall thrust, due to the passage of the thrust through sandstone, with the result that there is a concentration in the breach of the flow of solutions rising along a fault (in this case, the Barnum fault) striking parallel with it and truncated by it. An equally favorable condition would obtain at any point where the Black Wall and the Barnum faults happen to be cut by a later high-angle fault, provided that that brecciation along such later fault produces an effective breach in the Black Wall gouge.

The development of relatively high grade ore bodies along the Black Wall fault might be favored also under somewhat different conditions. If a fault with a large east-west component of strike were truncated by the Black Wall fault, then solutions rising along the breccia of the east-west fault would be forced to flow upward

(westward) in the (east-west) fault breccia just under the impervious Black Wall gouge, either to a breach in the gouge or to the surface. The Opalite fault in the lower Roy workings (see p. 28) is such a fault, and it did carry mineralizing solutions. Whether or not it continues far enough to the east, and whether or not the Black Wall thrust continues far enough to the north so that they intersect, and, if so, whether or not the Opalite fault is truncated by the Black Wall fault (as required by the theory) are not known. The Opalite fault is mentioned here merely to indicate that there are cross faults in this area, and that those faults, or some of them, carried cinnabar solutions.

There are, then, at least three different sets of structural conditions, each of which may be reasonably expected to occur, that would tend to favor the localization of high-grade ore bodies under or along the Black Wall fault. The nature and purpose of this study do not require any statement as to whether the possibility of the occurrence of such ore bodies justifies exploration of the Black Wall fault plane or the intersection of the Black Wall and Barnum faults by a northerly extension of the Roy drifts.

#### LOW-GRADE (SANDSTONE) DEPOSITS IN THE ROY-B.-M. MINE AREA

Sections A, B, and C in figure 6 indicate that the uppermost sandstone member of the Barnum stratigraphic unit occurs in the *hanging wall* of the Barnum fault below the level of the Black Wall thrust. Movement of solutions from the Barnum fault breccia into this sandstone bed may have been favored to some extent by the "backwater" effect of the Black Wall "dam", and may have been inhibited or accentuated locally by the presence or absence of clayey gouge on the hanging wall of the Barnum fault. As the special conditions leading to the concentration of flow that enriched the same sandstone in the Paradise area did not operate, there is no reason to expect high values in the sandstone bed in the hanging-wall block. It appears to have been worth mining in the stope above the Roy No. 3 level just south of the Grand Canyon (Jack's sandstone stope, see p. 21). Considerable stoping was done, and good values are reported from what is probably the same sandstone bed in workings about 110 feet above the Roy No. 3 level, accessible by a vertical raise 80 feet north of the junction of the Roy No. 3 drifts and haulage tunnel (fig. 4, section R-R). The same sandstone bed, or small cracks and fissures in it, carries some values on the surface above the mine workings just south of the Roy No. 4 portal, where the overburden has been removed in several prospect pits and trenches. The sandstone bed occurs at a number of other places in the mine workings—namely, in some raises from the Roy No. 3 level to the Black Wall, and in the Roy No. 4 and B.-M. No. 2 cross-cut tunnels. The fact that some values occur in the sandstone

bed at the three places mentioned above suggests the desirability of sampling the bed at all places where it is now exposed, to test the possibility that it may provide a large tonnage of low-grade ore. In this connection it should be noted that the bed is involved in a broad arch, whose east-pitching axis is in the general latitude of the Roy No. 3 crosscut tunnel, and that there may have been a tendency for concentration of flow (and hence of values) along the axis of this arch. If the results of the sampling show any promise, a large amount of additional information could be secured at small cost by tracing and sampling the outcrop of the sandstone bed on the surface in natural exposures and shallow pits.

#### THE OPALITE FAULT

The so-called "old Fisher workings", along the Opalite fault, are just north of the Roy No. 3 haulage tunnel, connecting with it at station 42. The fault strikes N. 52° E. and dips 80°-90° NW. The direction of slickensides indicates that the last movement has been chiefly strike-slip; as both walls are in the diabase of the Haulage laccolith, the displacement cannot be determined. Southwest of station 43 the breccia contains little or no visible cinnabar. Northeast of station 43 the showings are fair to good, and a brecciated zone from 2 to 5 feet wide has been stoped out for 70 feet or more above the level of the drift; the greater part of the old stopes are inaccessible at the present time. The ore differs from that along the Barnum fault in that the cinnabar is always associated with or enclosed in veinlets and irregular stringers of opal or quartz.

Mr. Kropf has cleaned out part of the old workings and has recently started mining the Opalite vein at the 1,160- to 1,170-foot level, about 80 feet above station 43 in the old Fisher drift. Since Kropf holds a lease on the entire Roy property, it is inferred that the values here are equal to, or better than, any known to him in the Roy workings on the Barnum fault. Relations seen in the Roy haulage tunnel and exposures of sandstone on the surface just above the present Kropf heading indicate that the drift on the Opalite fault will pass out of the Haulage laccolith into the overlying sediments within a short distance.

The favorable conditions for concentration of upward movement of mineralizing solutions (and hence, for the formation of better-than-normal values) that may occur at the intersection of the Opalite fault and the Black Wall thrust have been discussed earlier. The proposed Kropf drift, or raises from it, will encounter this intersection within 1,600-1,700 feet, provided, of course, that the faults do intersect and maintain observed attitudes (fig. 7). If the drift is in ore throughout this distance, no question of procedure is dependent on theoretical geologic relations. On the other hand, if values on the Opalite vein itself do not quite justify extension of the drift along it, there is much doubt as to how much dependence

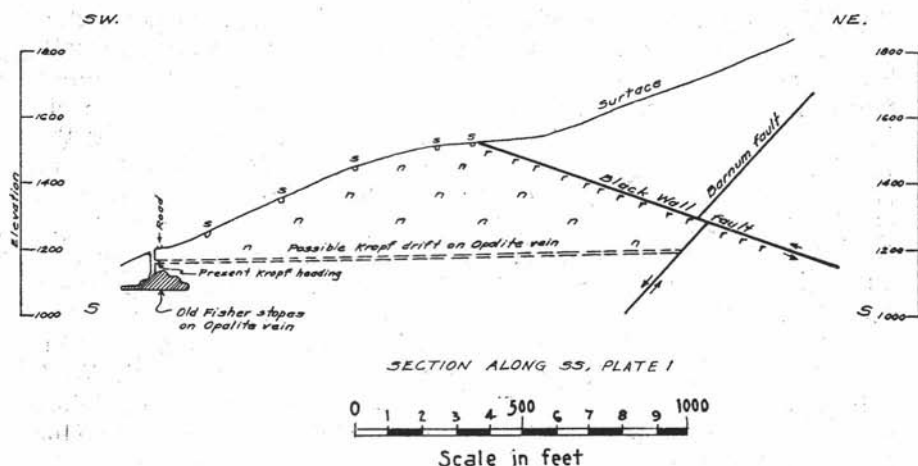


Figure 7. Hypothetical section along Opalite fault.

This section is based on assumptions (1) that the Opalite fault maintains the trend shown in the old Fisher workings, and continues in a northeasterly direction for at least 1,600 feet, (2) that the Barnum fault continues northward to the line of the section with a due north strike and  $45^{\circ}$  W. dip, and (3) that the Black Wall thrust continues northward to the line of the section with a N.  $15^{\circ}$  W. strike and a  $20^{\circ}$  E. dip. There is no evidence to support any of these assumed extensions of the faults; if the faults do intersect, it is likely that changes in strike and dip will shift the positions of the intersections from those shown. The section is therefore intended only to show the general nature of possible relations along the Opalite vein. Letters 'n' show possible 'normal' ore on the Opalite vein, and letters 'r' show possible relatively 'rich' ore on the Opalite vein just below the Black Wall thrust. The utility of tracing and sampling the outcrop of the Opalite vein (pits indicated by letter 's') is indicated clearly in the section.

should be placed on the theoretical possibility of finding rich ore at the Black Wall intersection. This doubt could be largely resolved, at small expense, by tracing the outcrop of the Opalite vein on the surface to where it is cut by the Black Wall fault, in order to determine whether there is actually a concentration of values at the intersection. (In this connection it may be worth noting that a large "boulder" of exceptionally rich ore is said to have been found some years ago on the hill slope on the strike of the Opalite vein and some distance below the supposed point of intersection.) Sampling and assaying of the Opalite vein in test pits for several hundred feet along its outcrop, and at the intersection, would provide a basis for determining the practicability of a mining venture.

#### THE PROBLEM OF THE SOUTHERLY EXTENSION OF THE BARNUM FAULT

As they approach the boundary between the Barnum-McDonnell property and the land to the east (NE  $\frac{1}{4}$  sec. 7, T. 12 N., R. 5 E.), the B.-M. No. 3 and the B.-M. No. 4 drifts split into two forks. The forks of the drifts, and the pattern of faults (and leads) which brought mining to a halt near the boundary are shown on the general map (pl. 1). Southward from their junctions with the respective crosscut tunnels both the B.-M. No. 3 and the B.-M.

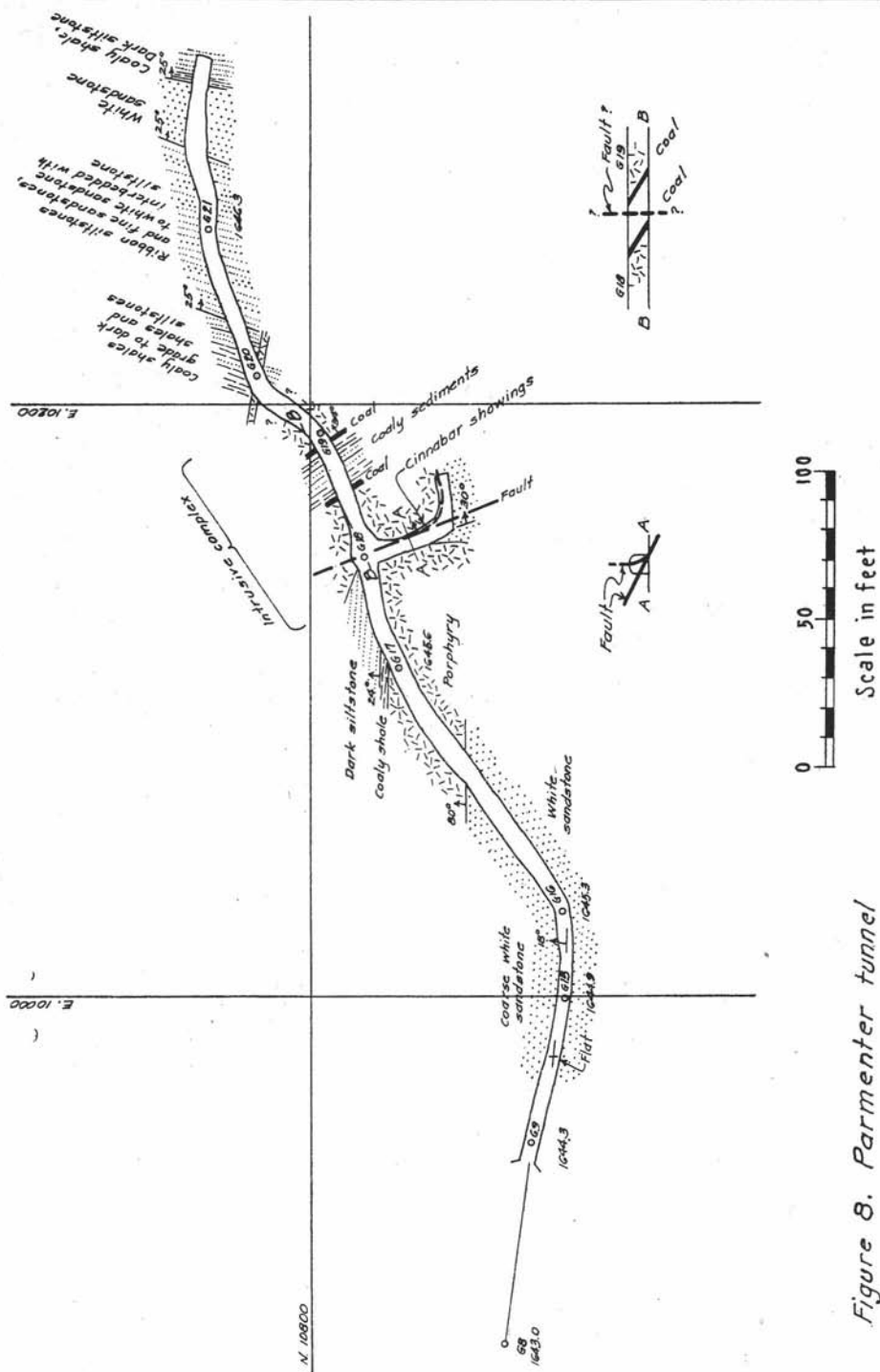
No. 4 drifts follow a well-defined brecciated zone, from 10 inches to 2 feet in width, and were reported to carry good values. In both levels the main Barnum fault splits into three (or more) minor faults, ranging from small gouge-filled fissures to 4-inch breccia zones, containing showings of cinnabar (pl. 2). Gouge along the small fault diverging southwestward from the B.-M. No. 4 drift, which was not followed, shows at least as good values as the fissures along which the drift was driven. Caved headings make it impossible to determine how far the minor faults were followed in either of the levels. The caved material at the heading of the west fork on the B.-M. No. 4 drift is said to mark the position of the so-called "Northern Pacific tunnel", a crosscut from the surface intended to pick up the lost vein. The east fork of the B.-M. No. 3 drift encountered glacial till, containing characteristic scratched pebbles, and was continued in this material for some distance (100 feet ?) before it was abandoned.

These relations—namely, the splitting of the Barnum fault into a number of minor faults—occur at several other places in the mine workings. They are generally local features, in that the main breccia zone is picked up within a short distance. The return of the principal movement to one plane may be due to a re-joining of the minor faults; but in some cases it appears that some of the minor splits may die out, only one of their number continuing past the split area as the main fault. The splitting of the fault at the south ends of the B.-M. No. 3 and B.-M. No. 4 drifts does not, therefore, indicate that the Barnum fault as a whole dies out in that locality.

It will be noted that there is a rough alignment of the eastern forks of the fault in the two B.-M. levels, suggesting a new directional trend. As normal faults, in general, are frequently characterized by abrupt and angular changes in strike, it seems quite as likely that the possible southerly continuation of the Barnum fault lies along the direction of the aligned east forks (S. 55° E.) as along the trend of the main fault north of this point. Plate 1, therefore, shows the traces on the surface of two possible southerly extensions of the Barnum fault—Barnum A being based on the assumption that the trend is S. 10° E., and Barnum B, on the assumption that the trend is S. 55° E.

The foregoing discussion deals with the possibility that the Barnum fault, as such, continues to the south or southeast. Even if it does extend southward, there is, of course, no evidence indicating that it is mineralized. Thus, while the trend lines described above are probably worth surface prospecting, no crosscutting or other subsurface exploration is justified.





## OTHER MINES AND PROSPECTS IN THE MORTON DISTRICT

## GENERAL STATEMENT

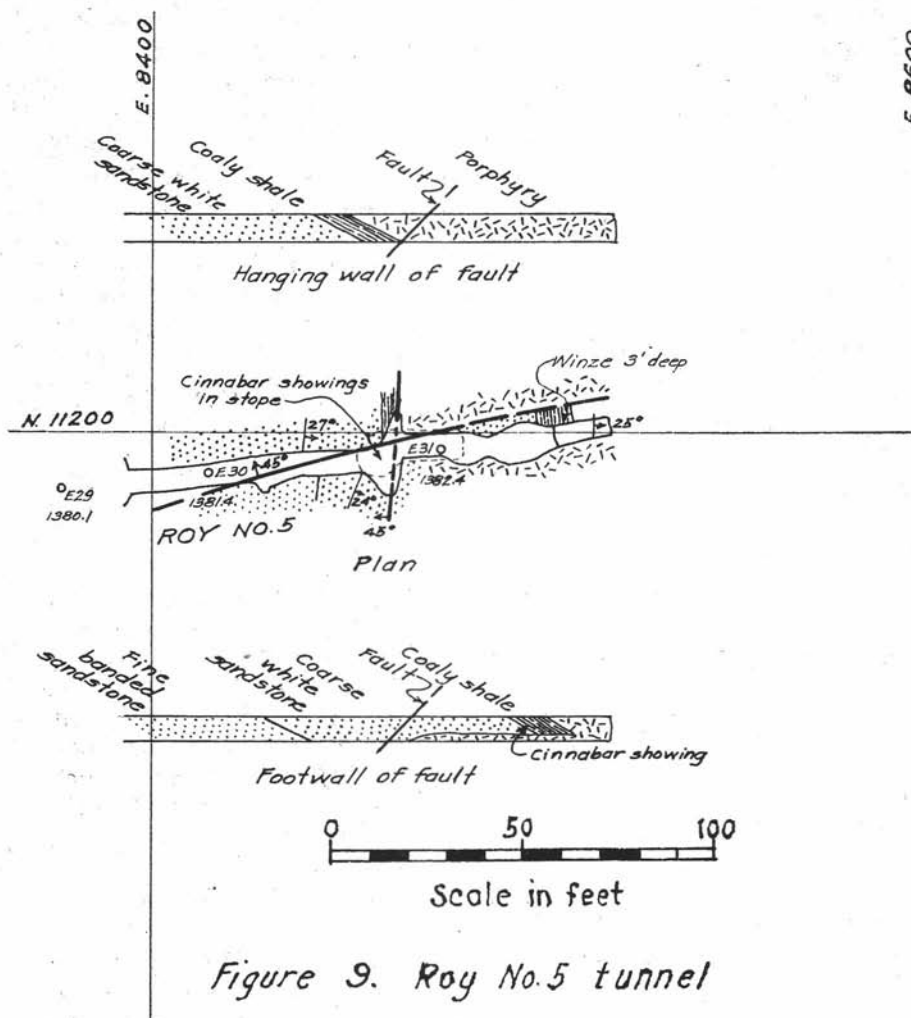
Natural exposures of bed rock are rare in the Morton district, because of a dense growth of vegetation and a thick mantle of residual soil, landslide and creep materials, and some glacial deposits. The smaller properties are, therefore, so far as geological observation is concerned, isolated features, and in most cases the individual underground workings are so small that they do not provide an adequate basis for an understanding of the structural factors that controlled mineralization. For this reason each opening or group of openings is described here as a separate unit; structural relations in the area as a whole are treated briefly in a later part of the report (see p. 42). The locations of the several properties are indicated on plate 1.

## THE PARMENTER TUNNEL

The portal of the Parmenter tunnel is near the east line of the SE $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 6, T. 12 N., R. 5 E., about 200 feet east of the north heading of the Roy No. 3 drift, and several hundred feet above the level of the highest Roy—B.-M. workings (pl. 1). The tunnel is 425 feet in length and trends in an easterly direction (fig. 8.). The first 210 feet is cut in a coarse white micaceous sandstone that shows prominent cross-bedding, and in dark carbonaceous shales and siltstones. The beds are flat-lying near the portal; east of station G15 they strike east and dip 18°-24° N. The last 110 feet of the tunnel (measured out from the heading) cuts similar rock types, which here strike N. 10°-15° E. and dip southeast. Between these two areas of contrasted strikes is a sheared and altered intrusive complex, involving carbonaceous shales and coal, porphyry, and a soft whitish material that may be altered sandstone or altered intrusive rock. As indicated in section B-B (fig. 8), the repetition of a coal bed 2-3 feet thick is probably due to a fault crossing the tunnel; the critical relations are hidden by lagging. At G18 a short drift follows a fault (or two intersecting faults, section A-A) showing a few inches of gouge and some cinnabar colors; the absence of stoping here, or elsewhere in the tunnel, suggests that the values were below those required for mining.

## ROY NO. 5 TUNNEL

The Roy No. 5 tunnel is in the NE $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$  sec. 6, T. 12 N., R. 5 E. It is 125 feet in length and trends eastward (see pl. 1). The tunnel follows a fault which strikes N. 70°-80° E. and dips 45° N., and cuts sediments that strike generally north and dip gently to the east (fig. 9). The south side, usually in the footwall block, shows



a sequence of sediments including fine dark-colored banded sandstone and siltstone at the base, grading upward into coarse white sandstone that is overlain, in turn, by black carbonaceous shale containing an impure coal bed. The same sequence appears in the north side (the hanging-wall block), but here the coal bed passes into the floor about 45 feet west of the place where it occurs in the footwall block; while the directions of slickensides at different places are not consistent, they suggest that both strike-slip and (normal) dip-slip movements have occurred. At station E30 plus 45 feet shallow pockets were cut into both walls and there is a small overhead stope in a brecciated zone which shows planes of slippage that strike north and dip  $45^{\circ}$  W. All the rocks in the vicinity of

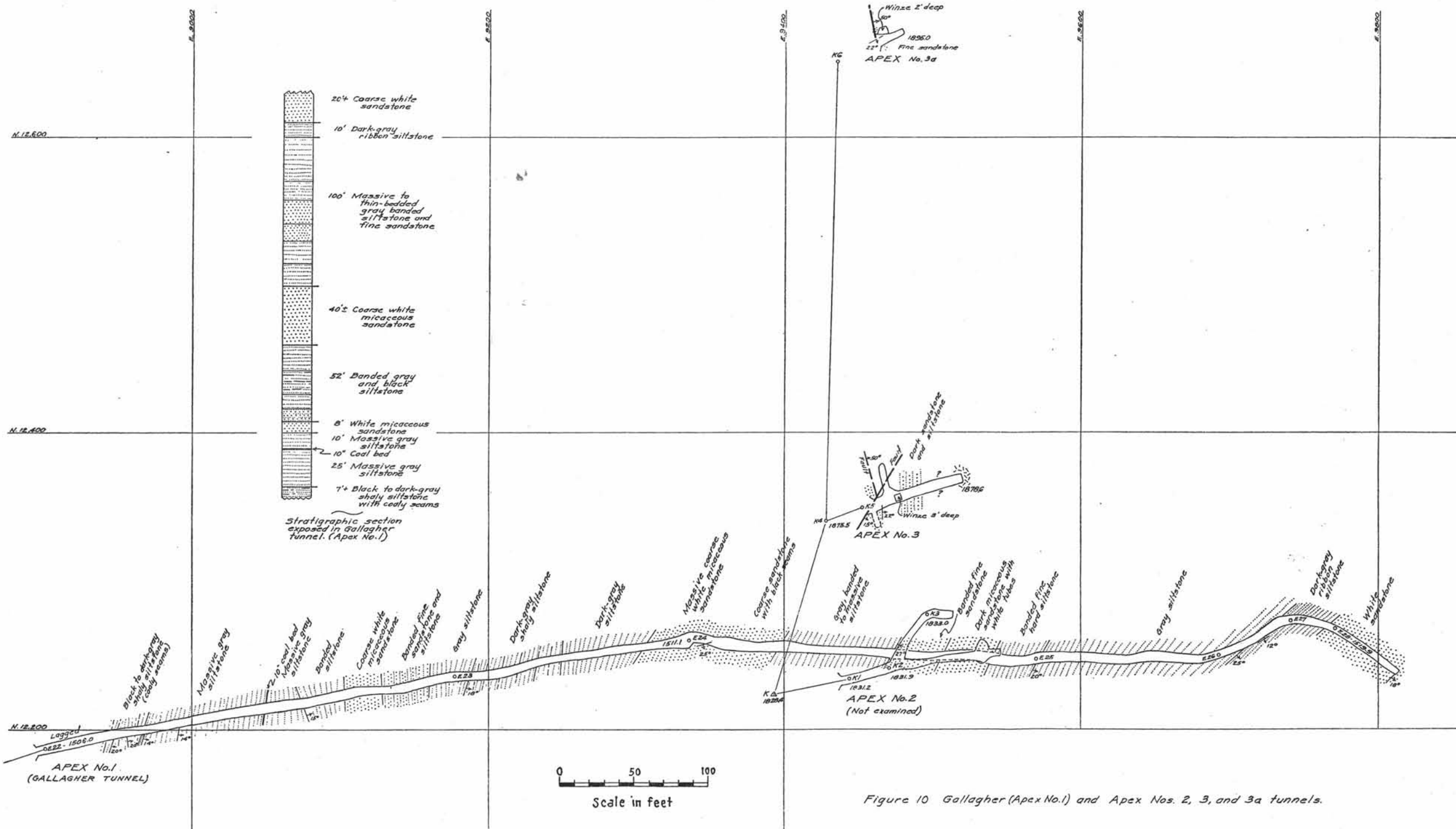
this cross fault are altered, alteration being especially marked in irregular masses of igneous rock which cut the sediments. There are some poor showings of cinnabar in the brecciated zone; in the south side, from 10 to 20 feet back from the heading, there are good showings of cinnabar in a small seam at a contact of coaly shale and an underlying whitish material, probably altered sandstone.

The Roy No. 5 tunnel is about 1,100 feet north of the Roy No. 1 (haulage) tunnel, and both show the same northerly strikes and gentle easterly dips. If these structural trends continue between the two tunnels, the horizon of coarse white sandstone of the Roy No. 5 tunnel would cross the Roy No. 1 tunnel where the Lower Massive sandstone occurs. The Roy No. 5 sandstone is similar to the Lower Massive in lithology, and both are overlain by dark-colored shales and a coal bed just above the contact; they are probably the same bed. As noted earlier, the bed carries disseminated cinnabar in Roy No. 1, and shows good cinnabar colors in Roy No. 5 near the contact with the overlying shales.

#### GALLAGHER TUNNEL

The portal of the Gallagher (or Apex No. 1) tunnel is in the center of the  $W\frac{1}{2}NE\frac{1}{4}SW\frac{1}{4}$  sec. 6, T. 12 N., R. 5 E. The tunnel is approximately 930 feet in length and trends eastward (see pl. 1). As shown in figure 10, the sedimentary sequence penetrated by the tunnel is made up of interbedded black shale, gray to black siltstone, and fine to coarse light-gray to white sandstone, the aggregate thickness being about 270 feet. In the first 700 feet from the portal the prevailing strike is  $N. 10^{\circ}-20^{\circ} E.$  and the dip averages  $20^{\circ} SE.$ ; the strike directions swing around to  $N. 45^{\circ}-50^{\circ} E.$  at the heading. There are no conspicuous brecciated or altered zones and no apparent values; the tunnel was probably driven to cut a "vein" exposed in the upper Apex workings, and failed to do so.

The Gallagher tunnel is about 1,800 feet north of the north end of the main Roy—B.-M. workings; and its position, more or less on strike with the three structural elements which control mineralization in the Roy—B.-M. mines (the Barnum fault, the Black Wall fault, and the bedding), suggests that it might provide a rough test of the continuity of these elements along the strike. If the Barnum fault and the Black Wall fault (1) continue northward and (2) maintain the strike and dip seen in the northern part of the Roy workings, the Barnum fault zone would lie within a few hundred feet east of (beyond) the Gallagher heading, and the Black Wall fault would crop out on the hill slope within 100 feet west of (below) the Gallagher portal. There is no evidence whatever that either of the faults continues northward to the latitude of the Gallagher tunnel; the point is that even if they did (and maintained their strike and dip) they would not be cut by the tunnel.





If the black shale of the highest Roy—B.-M. workings continues to the north, it should crop out in the approximate position of the Gallagher portal. The possibility that the black shale which occurs just within the portal is the equivalent of the uppermost shale of the Roy mine is of some interest, as an underlying coarse white sandstone (the upper member of the Barnum unit) is known to carry cinnabar in the Roy—B.-M. mines.

#### APEX NOS. 4, 5, AND 6 TUNNELS

The portals of the Apex Nos. 4, 5, and 6 tunnels, approximately 700-900 feet northeast of the Parmenter entry, are situated one over the other in a general north alignment on a steep south-facing hill slope, and the tunnels trend northward into the hill (pl. 1). The first 215 feet of the lowest tunnel (Apex No. 4) is cut principally in coarse white sandstone (fig. 11). The strike of the sandstone swings from N. 55° W. at the portal to N. 85° E. at the 215-foot point, where it is underlain by black shale containing a 2-foot coal bed near the contact. A fault marked by 1-2 feet of coaly-clayey gouge and breccia crosses the tunnel at this place. The fault strikes approximately east and dips 45° N.; drag on the coal bed in the footwall suggests that it is a thrust. As indicated on the map, a branch tunnel at station G12 crosses the same fault and curves back to cut it again near the heading. At G12 plus 55 feet in the branch tunnel a raise ascends along coaly fault gouge to a small drift or stope where the sheared zone shows some cinnabar colors. Dark-colored siltstone and sandstone in the hanging-wall block, as seen in the continuation of the main tunnel beyond the fault, vary in strike from N. 30° W. to due north—that is, the strikes are approximately at right angles to those of the foot-wall block.

At a place 12 feet from the portal in the next higher tunnel (Apex No. 5) a fault striking N. 80° W. and dipping 34° NE. shows coaly gouge and breccia ranging from a few inches to 2 feet in thickness. A coarse white sandstone which forms the hanging wall at the fault is seen to rest on dark-colored shales and a 2-foot coal bed in the left fork of the tunnel a short distance north of the fault. As indicated in the structure section, the fault is certainly the same as that seen in the Apex No. 4 workings; if, as seems probable, the sandstone-coal contact in the footwall block in Apex No. 4 is the same as the sandstone-coal contact in the hanging-wall block in Apex No. 5, the fault is a thrust causing about a 60-foot offset of the beds.

The roof of the tunnel at G11 and a 20- by 10-foot overhead stope at the tunnel junction (see fig. 11) show conspicuous disseminations and seamlets of cinnabar at places in the coarse white sandstone. It will be noted that here, as at all other places where cinnabar is

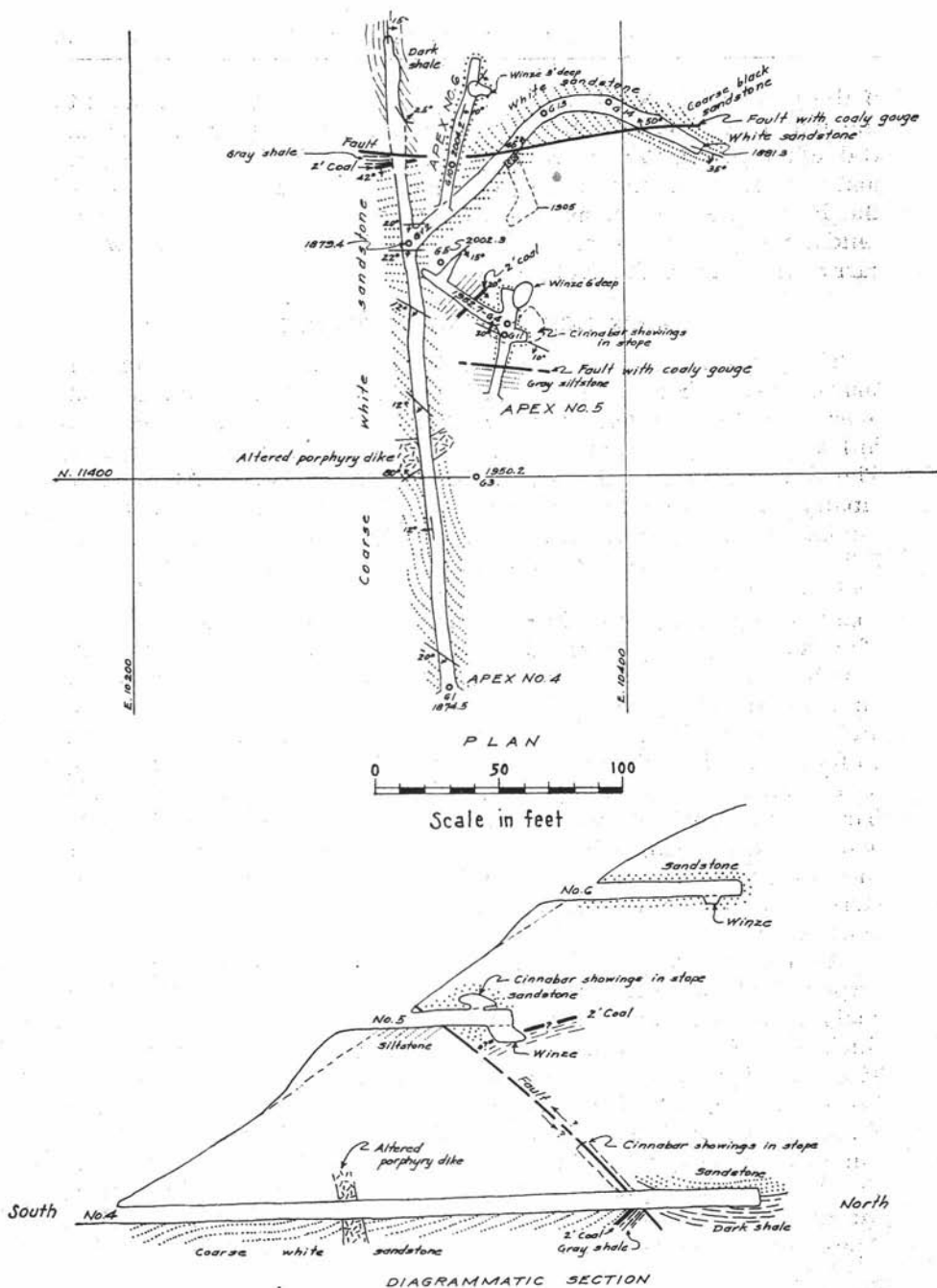


Figure 11 Apex Nos. 4, 5, and 6 tunnels.

disseminated in sandstone beds, the mineralization occurs where the pervious sandstone has a favorable attitude in the hanging-wall block, adjacent to a fault which acted as a conduit for ascending solutions.

Apex No. 6 is a short tunnel cut entirely in sandstone. It is undoubtedly in the hanging-wall block, with reference to the Apex Nos. 4 and 5 fault, and it is interesting to note that the general northerly strike and easterly dip, which prevail in the hanging-wall sediments in Apex Nos. 4 and 5, are seen also in Apex No. 6. Whether the Apex No. 6 sandstone is the same as the sandstone of the Nos. 4 and 5 levels is not known; no cinnabar colors were observed.

#### LYTLE-LYNCH NOS. 2, 3, AND 4 TUNNELS

The Lytle-Lynch workings are in the SE $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 6, T. 12 N., R. 5 E. They consist of three tunnels which are still accessible, and at least two caved workings, oriented as shown in figure 12. The Lytle-Lynch No. 3 tunnel, 230 feet in length, cuts through a sequence of white sandstones and gray banded siltstones and one 2- to 3-foot coal bed, the prevailing strike being N. 60°-70° W. and the dip, 20° SW. Two faults which cross the tunnel are evidently minor features; neither one is accompanied by any considerable brecciation or alteration, and no cinnabar colors were noted. Lytle-Lynch No. 2 is largely lagged; a number of caves and squeezes and the general condition of the timbering and lagging indicate that it will soon be inaccessible. The tunnel is cut in an intensely sheared and altered intrusive complex which includes two main rock types—(1) a soft whitish altered igneous rock, and (2) a coarsely granular rust-colored micaceous material, probably an altered sediment. At the heading a banded structure, probably bedding, strikes east and dips 20° S. The form of the hillside above the tunnel indicates recurrent large-scale landslide movement, undoubtedly due largely to the unstable condition of the sheared and altered rock seen in the tunnel.

Pyrite (or marcasite), which is sparingly present in altered zones in several of the other workings, is notably abundant in Lytle-Lynch No. 2. Seamlets of cinnabar occur at several places in the tunnel, and it is reported that "all" the brown granular material shows colors in a pan and will run from 2 to 3 pounds of mercury per ton. The position of the portal of a tunnel that is now completely inaccessible is marked by caving at the surface and crushed timbers a few feet east of the Lytle-Lynch No. 2 portal and about 6 feet below its level. The following notes regarding it, all hearsay, are included for what they are worth: The tunnel was driven by Jack Rosborough for a former owner or lease holder. He states that it trended about N. 20° E. and was 90 feet long. The

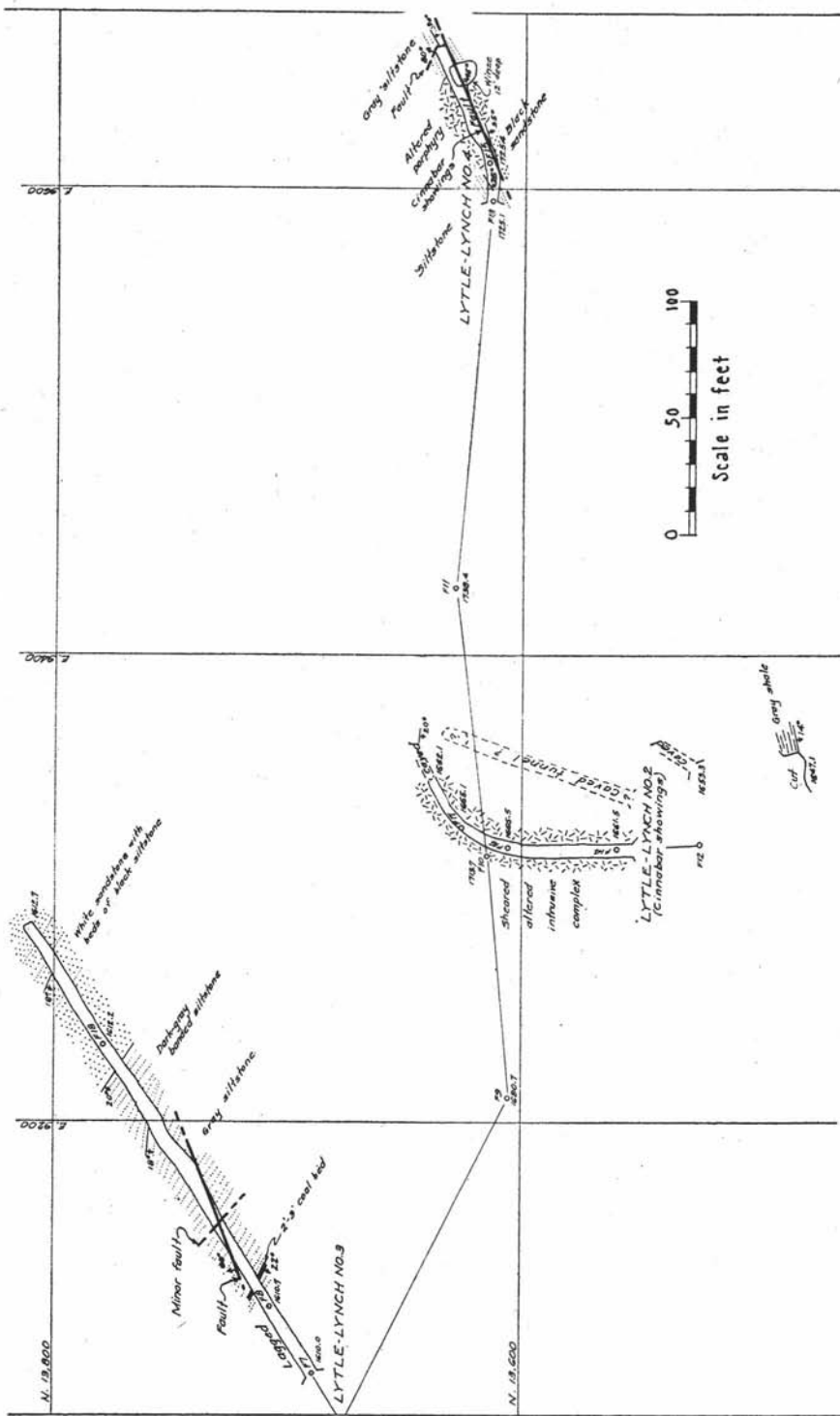


Figure 12. Lytle-Lynch tunnels.

tunnel was in "bad" ground, similar to that in Lytle-Lynch No. 2, throughout its length; but a 4-foot winze at the heading encountered a "hard-rock footwall", which slopes  $20^{\circ}$ - $30^{\circ}$  in a southeasterly direction. This is of some interest in that it suggests the position and approximate trend of one wall of the sheared zone in which Lytle-Lynch No. 2 is located. Rosborough stated that 4 or 5 parallel zones of cinnabar-carrying material, each from 3 to 4 feet in thickness, were encountered in the tunnel.

The Lytle-Lynch No. 4 tunnel follows the trend of a brecciated zone along a fault which strikes N.  $60^{\circ}$ - $70^{\circ}$  E. and dips  $45^{\circ}$  SE. The footwall block is siltstone for 10 feet from the portal, altered porphyry from here to the winze shown on figure 12, and siltstone from the winze to the heading. The hanging-wall block shows dark-colored sandstone and siltstone throughout its length, except that altered porphyry makes up the lower part of the side 35 feet from the portal to the winze. The sediments strike N.  $60^{\circ}$ - $70^{\circ}$  E. and dip  $25^{\circ}$ - $35^{\circ}$  SE. The fault breccia contains good showings of cinnabar at several places, and the "pay seam" is said to widen downward in the winze that was sunk on it. The winze is now filled with water; specimens reportedly taken from the bottom are very high grade ore.

#### THE SPENCER MINE AND WORKINGS IN VICINITY

The Spencer tunnels are in the NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 1, T. 12 N., R. 4 E. (see pl. 1). As shown on the detailed map (fig. 13), the southernmost, or No. 1, of the two Spencer tunnels has collapsed, its trend being shown by a strip of caved ground. The northernmost, No. 2, Spencer tunnel is blocked by a cave 60 feet from the portal and is tightly lagged to this place. The fact that the dump of the No. 2 tunnel contains an estimated 1,000-1,500 cubic yards of waste indicates that the underground workings were relatively extensive. A large collapse pit (at 'A' on the map) is 230 feet southeast of the No. 1 portal; it has walls of soft, earthy material, probably decomposed porphyry, and is undoubtedly formed by the caving of part of the Spencer workings. Other than this, nothing is known with regard to the extent of the mine, the nature or trend of the ore body, or the production.

A pit, 'B', has been dug 50 feet south of the collapse pit; its south side parallels the trend of a fault which brings altered porphyry into contact with a coarse rust-colored micaceous sandstone. The same rock types are in fault contact in another pit, 'C', about 120 feet to the northeast of pit B. The sandstone south of the fault strikes N.  $60^{\circ}$ - $70^{\circ}$  W. and dips  $15^{\circ}$ - $20^{\circ}$  SW.; it is traversed by a prominent north-south joint system.

In the southwest corner of pit B a 3- to 6-inch seam contains veins and discontinuous small lenses of solid cinnabar as much as





three-eighths of an inch in thickness. The seam, which is exposed for only a few feet, lies in a north-south joint in sandstone immediately adjacent to the east-trending fault. About 5 feet to the east a second north-south joint shows good values in cinnabar near the fault. A shallow trench extending south along the trend of the joint is now floored by caved material; a 7-foot shaft at the south end of the trench shows no mineralization along the joint, and no colors were noted in prominent north-south joints in sandstone in several other shallow pits and trenches immediately to the south. A 6- to 14-inch brecciated zone along the fault includes seamlets of cinnabar in the southwest corner of pit B, and it is reported that the main lead of "rich" ore below the surface (as seen when the pit was being worked) trends east-west. This indicates that here, as elsewhere in the Morton district, the fault breccia served as the principal conduit for the mineralizing solutions, and that the narrow discontinuous leads in the joint cracks are offshoots. The absence of cinnabar colors in a narrow brecciated zone on the fault in the trench at 'C' suggests that some unknown factors caused a localization of mineralization on the fault in the vicinity of pit B.

According to an unpublished report<sup>①</sup> there are two old tunnels and several trenches in the SE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 36, T. 13 N., R. 4 E., about 2,000 feet northeast of the Spencer workings. The trenches were opened in 1937 in connection with a State mineral survey project, sponsored by the State Department of Conservation and Development and Department of Public Lands. Cinnabar was encountered in one of the old tunnels and in two of the trenches along a southeastward-striking fault zone, but as these workings were unknown to the writer at the time of his field studies in 1942, no investigations of them were undertaken.

#### PETERSON TUNNEL

The Peterson tunnel is near the center of the NE $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 1, T. 12 N., R. 4 E. (see pl. 1). It is 87 feet in length and trends eastward, following the intersection of two faults striking east, one of which dips 80° N., and the other, 20°-30° S. There are no stopes and, so far as could be determined (the tunnel contains from 1 to 2 feet of water), no conspicuous showings of cinnabar along the faults. The tunnel is cut in a light-gray to white granular rock, which appears like a tuffaceous sandstone but is actually an altered diabasic rock. It is divided by several sets of closely spaced (from 2- to 6-inch) joints into a block pattern, particularly striking in appearance because of dark-brown staining that is marginal to each joint. The white interiors of the brown-rimmed joint blocks carry

<sup>①</sup> Knowles, P. H., Cinnabar deposits of the Morton district, State Wide Mineral Survey, Works Progress Administration, September 6, 1939. (Manuscript in files of State Division of Mines and Mining.)

finely disseminated pyrite crystals, suggesting that the staining is an oxidation effect. A specimen from the tunnel failed to show cinnabar colors when pulverized and panned.

## **SURFACE GEOLOGY AND GENERAL STRUCTURAL RELATIONS**

Because of the heavy cover of soil and vegetation, time spent in traverses on the surface in the Morton district yields relatively poor returns in geologic data. As indicated earlier, it is possible to correlate beds between different parts of the same mine or adjacent mines, the correlation being based on distinctive rock types or on distinctive sequences involving several rock types; but virtually the only rock types which make surface outcrops are coarse sandstones and some igneous rocks. As four or five different sandstone beds occur in the underground workings, and as these beds are (megascopically) similar in lithology, it is unsafe to correlate between scattered sandstone exposures on the basis of apparent lithologic similarity. Careful microscopic study might discover special index minerals in one or more of the sandstones which would permit their use as key beds in mapping.

Zones of weakness along faults are sometimes reflected in topographic forms which serve to indicate the occurrence and trend of the faults. As is mentioned on page 43, it is likely that one stream valley in the Morton cinnabar area follows a fault line. However, such faults as the Barnum usually produce crush zones less than 2 feet in width, and it seems unlikely that these minor features would exert a controlling influence on erosional processes, and the recency of glaciation makes it still less likely that they would be reflected in the present topography. Certain small valleys and saddles crossing spurs and divides may be related to faulting, but since they may have been formed equally well by ice erosion or meltwater streams during the last glacial stage they cannot be used with confidence in mapping.

The dip and strike symbols on the accompanying structural and topographic map (pl. 1) indicate the attitude of beds at various places in the underground workings and on the surface. The dash-dot lines are simply smooth curves connecting the strike symbols, and are intended to convey a general picture of probable structural trends. They are not drawn on any particular bed, and their spacing is not mathematically related to dip, hence they are structural-trend lines rather than structure contours. The dash lines, representing faults, are in all cases based on observations underground, and, with the exception of the Opalite, Barnum A and B, and Black Wall faults, are drawn at the elevations where they were actually seen in the underground workings. The Barnum fault is indicated as it appears in the Roy No. 2—B.-M. No. 4 levels by name only; to indicate it by dash lines would obscure that part of the

workings, as the latter are in the fault plane. The surface trace of any of the faults can be determined by simple graphical methods (on the assumption that the faults extend to the surface and maintain their dip and strike in so doing) by using the given strikes, dips, and elevations, and the altitudes indicated by the surface contours. This has been done for the Opalite, Barnum A, Barnum B, and Black Wall faults, and their theoretical surface traces are indicated on plate 1.

The structural-trend lines indicated in the southeastern part of the map are relatively well controlled. In the area of the Roy—B.-M. mines, departures from the prevailing north strikes are known to be due in large part to the presence of intrusive bodies. The north strikes continue northward through the Roy No. 5 workings and then swing eastward through the Gallagher and Apex Nos. 2 and 3 workings, suggesting that an adjacent synclinal axis to the east pitches southward. The Parmenter and Apex Nos. 4, 5, and 6 tunnels appear to be near the synclinal axis, the irregular strikes and dips in these workings being reasonably explained as the result of the minor drag folds, which often occur along the axes of large flexures. Faults of small displacement in such minor folds could readily produce the sharply contrasted strikes and dips noted in the description of these properties.

Similarity in strike and dip and a fair alignment in trend suggest that the Apex No. 4 fault may be a continuation of the Roy No. 5 fault. However, it should be noted that the apparently perfect alignment of the two faults on the map is deceptive in that it does not take into account the difference in elevations at which they are plotted. If either fault is continuous for any considerable distance between these two tunnels, it may cut or be cut by the Black Wall thrust, thus making a favorable condition for mineralization discussed earlier in connection with the Opalite vein.

In the northern part of the map area data are meager; most observed strikes are easterly and the dips are southerly. Variations from parallelism may be due to minor tectonic warps or to the presence of intrusives. Similarity in strike and dip and a fair alignment suggest that the steep fault of the Peterson tunnel may be a continuation of the Spencer-area fault.

Between the southeastern part of the map area, with north strike trends, and the northern part of the map, with east strike trends, lies the relatively deeply incised and straight valley of Chapman Creek. Minor faults in Lytle-Lynch Nos. 2 and 4 strike parallel with the trend of the valley, and a zone of intense shearing and hydrothermal alteration (Lytle-Lynch No. 3) lies between them. The valley is now being extended headward at a relatively rapid rate by landsliding and other types of mass movement in the sheared and altered material. These relations, taken together,

suggest that the Chapman Creek Valley marks a major structural break, probably a fault zone.

## CONCLUSIONS WITH REGARD TO HABITS OF MINERALIZATION

As indicated earlier, the purpose of this study was (1) to ascertain the geologic factors which controlled mineralization in existing underground workings in the Morton district, in order (2) to evaluate the probability of extension of the mercury ores onto adjoining lands. The relations of structure and stratigraphy to mineralization in the district (that is, the first objective) may be summarized in terms of three main types of ore occurrences or possible ore occurrences—(a) the 'breccia' type, (b) the 'sandstone' type, and (c) the 'intersection' type.

(a) Brecciated zones along faults served as the main, or primary, avenues of upward movement of mineralizing solutions. The flow of solutions in these zones was due essentially to the greater perviousness of the fault breccia relative to the bedded sediments cut by the faults; it may have been due in part to the presence of a discontinuous sheet of impervious gouge, along the hanging walls of the faults, which tended to prevent leakage from the breccia zones into moderately pervious sandstones in the hanging-wall blocks. The greater part of the production of the district to date is from the breccia zone along the Barnum fault, and the Barnum ore body may be taken as an example of the breccia-type ore body. The breccia-type occurrence is defined as one in which mineralization was effected by solutions moving upward along a fault, without notable concentration of flow in any part of the breccia by reason of cross faults or other special structural features.

Local variations in the tenor of ore in the breccia type of occurrence probably reflect variations in the perviousness of the breccia, and these variations in perviousness are probably due largely to differences in the (fracturing vs. shearing or sliding) characteristics of the rocks cut by the faults. However, there does not appear to be any conspicuous and consistent correlation between any particular rock type in the hanging wall or footwall of any of the faults and mineralization along it. Neither does there appear to be any conspicuous and consistent correlation between tenor of ore and specific rock types which is due to the chemical effect of wall rocks on the mercury-carrying solutions; there is a tendency for somewhat better showings of cinnabar in coal and coaly sediments than in noncarbonaceous beds, but it is probably too small to have any significance in the planning of mining operations. The Barnum fault surface is fluted, varying from place to place in strike and dip, but there is no conspicuous and consistent relationship between arches and troughs on the fault surface and mineralization in the Barnum breccia.



Observed cinnabar deposits in the Morton district have a vertical range of about 950 feet, from the lowest to the highest workings (B.-M. No. 6, 1,000 feet elevation, to Apex No. 5, 1,950 feet elevation). As the only observed primary ore mineral is cinnabar itself, and, as the associated pyrite and chalcedonic silica are non-committal, there is no basis for any statement as to whether any given mine level or drift is near the top or the bottom of that pressure-temperature zone where conditions were right for the precipitation of the mercury content of the ascending solutions. In so far as the facts at hand are concerned, values on the breccia-type ore body may continue to greater depths than now known; they may continue well above the highest observed showings, or they may do both. Detailed assay mapping might shed some light on this phase of the problem.

For these reasons, structural and stratigraphic studies of the faults, ore, and rocks cut by the faults contribute little that is of practical value, as they do not permit prediction of continuity or changes in values, laterally or vertically, on any ore body of the simple breccia type. In this type of occurrence, mercury is "where you find it."

(b) Under favorable circumstances some fraction of the mineralizing solutions passed from the primary (breccia) avenues of movement into sandstone beds and continued its ascent along these beds. Favorable circumstances include—(1) perviousness of the sandstone, (2) an attitude of the bedding in the hanging wall of the feeder fault such that up-dip movement was possible, (3) the absence of a tight seal of gouge on the hanging wall of the fault, and, possibly, (4) some kind of blockade higher on the feeder fault which prevented or inhibited free movement upward along it. The sandstone-type occurrence was, in other words, formed by a diversion or dispersal of flow of some portion of the mercury-carrying solutions, and it may be expected to be lower in tenor than associated breccia-type ore. The sandstone ore is important because it may provide a large tonnage of low-grade material of a variety that is relatively inexpensive to mine, and which lends itself readily to various kinds of concentration in milling.

There is no sharp demarcation between the breccia and sandstone types of occurrences. The several workings illustrate every gradation between (1) disseminated cinnabar in unbroken sandstone (the Lower Massive in the Roy No. 1 level), (2) disseminated cinnabar and seamlets of cinnabar in very small cracks (overhead stope in Apex No. 5), (3) rich seams of cinnabar in well-defined joints (pit B in the vicinity of the Spencer tunnels), and (4) the typical fault-breccia type.

It is not to be expected that values will be uniformly distributed laterally or throughout the full thickness of any given sandstone

member. It might appear, on first thought, that the values in a given sandstone should be "better than average" near the contact of the sandstone and an overlying impervious shale, and/or along the axes of pitching arches in the sandstone member. However, this phase of the theory of structural control should *not* be adopted as a guide in the sampling of any bed. If ascending mercury-carrying solutions were, like oil, lower in specific gravity than other liquids occupying pore space in the sandstone, this 'cap-rock' relationship might operate as a control for movement within a sandstone member. There is every reason to believe that the mercury-carrying solutions moved upward, not because they were floated up on heavier liquids, but because of a continuing supply from depth, or because they were forced from areas of greater to lesser hydrostatic pressures. For this reason, the arched cap-rock (oil accumulation) theory probably has little or no bearing on localization of movement of the mineralizing solutions in a given sandstone member; if any localization occurred, it was probably controlled primarily by variations in perviousness within the sandstone. The point of practical importance is that sandstone members known to carry values should be sampled foot by foot.

(c) A concentration of flow of mineralizing solutions is to be expected at places where the continuity of pervious zones (as brecciated feeder-fault planes) was interrupted by cross faults; the relatively rich ores that may result are the intersection type. One example is that in which the feeder fault, carrying impervious gouge, is cut by a later fault with the same general strike; the result may be a lateral diversion of flow along the feeder fault below the wall of gouge toward and through any breach in the wall (the Paradise-Nigger Heaven interpretation). Another example is that in which the feeder fault is cut by a later gouge-carrying fault striking at a high angle to it, with a resulting concentration of flow in the breccia of the feeder fault below the gouge wall and up the dip of the gouge-carrying fault (intersection of the Opalite and Black Wall faults?). A number of other varieties of intersections of bedding or faults by later fault planes may give rise to the concentration of flow of mineralizing solutions that is the essential requirement for development of the intersection type of ore body.

These general principles are based largely on observations in underground workings in secs. 6 and 7, T. 12 N., R. 5 E. They probably apply also in sec. 1, T. 12 N., R. 4 E., where rock types and general structural relationships are similar; but scarcity of surface exposures make it unlikely that any specific fault can be traced from sections 6 and 7 into section 1, and the absence of known key beds makes correlation of sedimentary units uncertain. As it is virtually impossible to work out a definite and detailed stratigraphic sequence on the basis of surface exposures,

surface stratigraphic and structural study in section 1 is of little use in finding faults; and, as indicated earlier, the physiographic criteria for faulting are unreliable. Even if the faults could be found, geologic relations contribute little to the understanding of the distribution of values along them. For these reasons, the findings in sections 6 and 7 do not serve to define favorable prospecting areas in section 1.

The showings of cinnabar in small surface exposures in pit B near the Spencer tunnels may be as good as any of the original surface showings in sections 6 and 7. The only recommendation justified by the facts at hand is that exploration in this area should be encouraged. The possibility that the ore continues east or west along the fault exposed at pit B can be tested at small expense by trenches or test pits on the outcrop of the fault. Sinking on the fault at one or more places for a distance sufficient to establish its attitude and to determine whether the ore has any continuity in depth (and whether it may have been largely mined-out in the old Spencer operation) should precede any more elaborate development work. It is in the development or exploration stage, rather than in preliminary prospecting, that the general principles outlined above, especially as they apply to the 'sandstone' and 'intersection' types of occurrences, may be of practical value to the operator.



